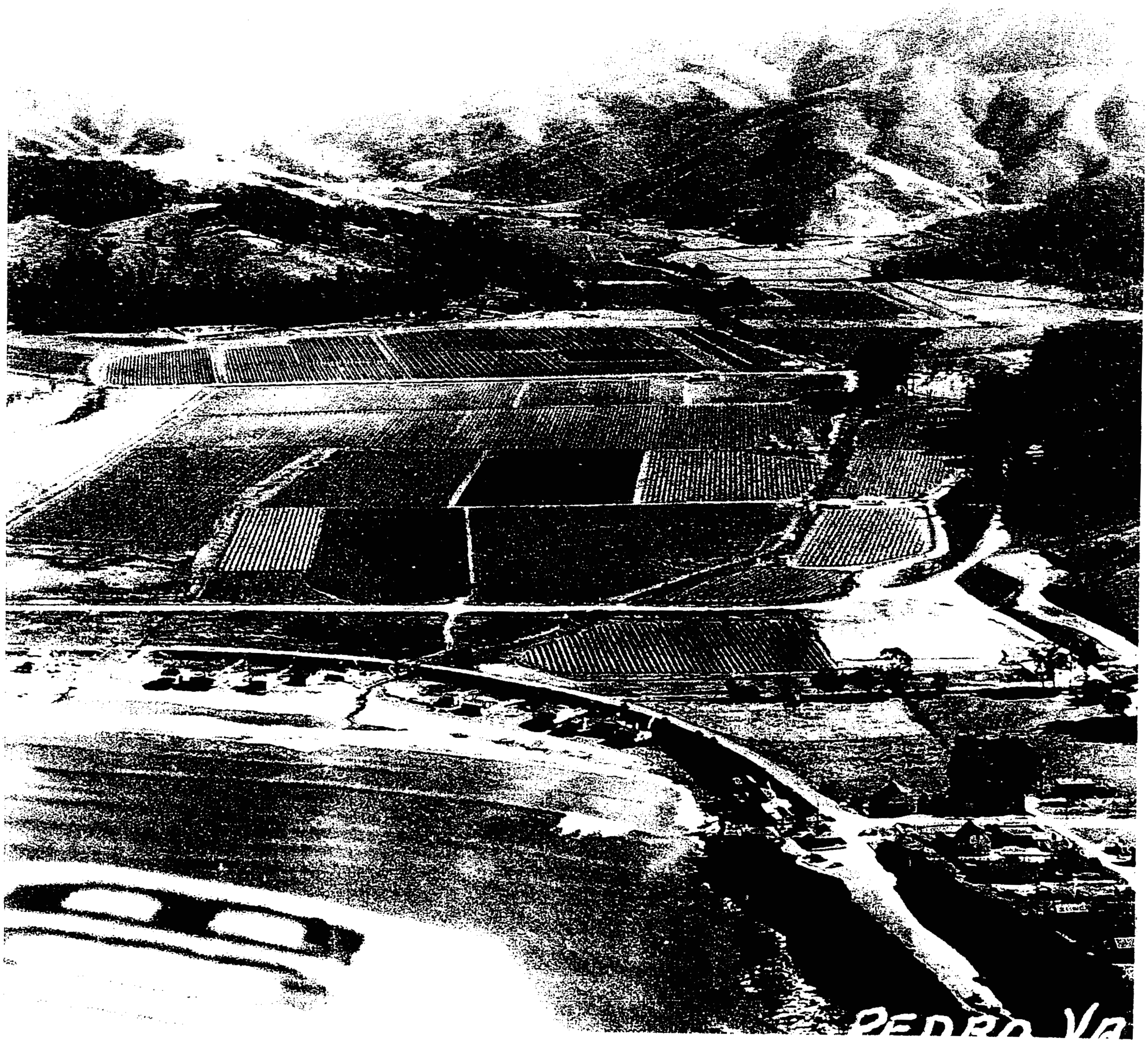
SAN PEDRO CREEK GEOMORPHIC ANALYSIS

by

Laurel Collins, Paul Amato, Donna Morton

March, 2001



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ABSTRACT

San Pedro Creek flows westerly to the Pacific Ocean, draining an 8.2 sq mi watershed in Pacifica, San Mateo County, California. Our Study Site, which includes the lower 2.6 miles of the creek, was analyzed to determine current physical conditions and impacts of land use activities. The San Pedro Creek Watershed Coalition provided funding from the San Francisco Bay Regional Water Quality Control Board. This report provides science-based and process-related findings so that future restoration and management efforts focused on San Pedro Creek will have increased potential for success and cost effectiveness.

Land use impacts from cattle ranching, croplands and suburbanization have increased rates of sediment supply and amount of runoff from San Pedro Creek. Bank erosion and flooding has caused property damages and economic losses to the community. The numbers of migratory steelhead fish and abundance of their habitat has declined dramatically. Citizens and land managers have increasing concerns about the ecological health of the watershed. We present a timeline of significant landscape impacts, document present physical conditions, and discuss how channel processes have responded to the variety of land use activities.

Some of the most significant changes that San Pedro Creek has undergone since its settlement 217 years ago by non-native people include the following:

• San Pedro Creek is longer by 0.8 mi because it flows into a constructed drainage ditch.

• The Creek flows directly to the Pacific Ocean. It has lost access to its previous wetland and a fresh water lake.

• Most of the former Lake Mathilda and its associated wetland has been destroyed.

• The creek has become deeply entrenched, incising as much as 16 ft in some areas, loosing access to its historic floodplain. We roughly estimate that 217 years ago it may have been no more than 5 ft deep along the middle reaches of our Study Site.

• Greater than 4 mi of tributary channel length has been put into underground culverts.

• 13% of the watershed surface area is impervious (EOA, 1998).

• Over 1 mi of the bank length along the Study Site has artificial revetment. Most of the revetment is concrete, riprap, and sackcrete.

• Over 1.9 mi of the Study Site bank length is in an eroding condition.

• Runoff, flood magnitude and frequency has increased as a response to land use activities.

• Water table elevation of the valley floor has lowered from draw down along the entrenched channel banks and from construction of the drainage ditch.

• Large woody debris in the channel is often removed or modified for flood passage.

• Structures have created impassable barriers for migrating steelhead under certain flow conditions.

• Most of the pools in the Study Site that are deeper than 1 ft during low flows are not caused by natural mechanisms; instead, they are inadvertently caused by man-related structures.

• There are at least 10 remnant dam or weir structures that once crossed the channel within the Study Site.

• The amount of sand and finer-sized sediment on the bed surface within the Study site is about 22%. We expect that the amount of fines is greater now than historically.

• For the Study Site, the long-term rate of sediment supply from bank erosion is 46 cu yd/yr. For bed incision the sediment supply rate is 342 cu yd/yr. The combined long-term supply rate from both bed and banks is 388 cu yd/yr. This rate is considered to be greatly accelerated from conditions that existed prior to non-native settlement.

• The proportion of sediment supply that is conservatively estimated to be related to anthropogenic activities is at a minimum 60%.

What can be done? Now that we know that much of the sediment supply is from instream and adjacent land use activities we can focus future restoration efforts on activities that will not reinvent past mistakes and not throw money at poorly conceived projects that have minimal effect upon decreasing bank erosion or sediment supply. By recognizing the responsiveness of channels to instream and adjacent land use perturbations and by designing restoration programs that permit natural processes, it is possible to promote channel stability, ecological diversity, and viable habitat in a naturally functioning system. The following recommendations are given with this goal in mind.

1. Where possible, reduce accelerated rates of bank erosion and bed incision to reduce property loss and input of fine sediment to the channel, but minimize the use of unnatural instream structures for stabilization. Instead, consider reshaping the channel cross section to a stable form, use biotechnical stabilization methods, or use boulder veins to direct flow away from eroding banks. Channel reshaping could be accomplished by surveying cross sections in the stable B type Rosgen Stream Class to potentially construct similar geometry (where appropriate) in the F and G classes.

2. Increase the width of the riparian buffer along the channel, especially where vegetation is presently missing. Promote the replacement of non-native invasive vegetation with native species to improve riparian habitat.

3. Increase the potential for LWD recruitment by not removing or modifying LWD unless it threatens a structure or causes backwater flooding at bridges, and by performing recommendation # 2.

4. The longitudinal profile of the mainstem channel should be surveyed to establish future monitoring stations that will show changes in bed elevation and correctly define terrace heights and stream gradient. The profile should be detailed enough to define pool riffle morphology.

5. Consider long-term funding solutions for 1) restoration projects; 2) future bridge designs that will not interfere with large floods, the passage of LWD, and the transport of sediment; 3) subsidies and incentives for landowners to stabilize banks using methods discussed in recommendation #1; and 4) long-term monitoring San Pedro Creek as an Observation Watershed for future change.

6. The rest of San Pedro Creek Watershed should be assessed for sources of sediment resulting from land use and instream activities upstream of the Study Site. The quality of water and habitat in mainstem and tributary reaches should be assessed. It is important that the remaining fragments of high quality channel habitat be maintained into the future.

7. Consider opportunities to ameliorate increased, flashy flows from the urban areas by constructing floodplains, off-channel habitat, wetlands, and lakes (consider the previous functions of Lake Mathilda).

8. Redesign the Capistrano fish ladder and downstream pool. Also modify or redesign the upstream 640' long, concrete-walled channel to improve fish migration by incorporating resting areas into the channel geometry.

9. Investigate whether there is potential to daylight portions of North Fork to increase salmonid habitat and reduce velocities above the confluence with the mainstem channel..

10. Historical questions about the extent of wetlands or frequency of native burning practices cannot be answered by this study, but a program of coring select parts of Lake Mathilda and the valley floor could provide some resolution.

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To coyote, eagle and hummingbird whom which the Ohlone people evolved their mythology and nourished themselves of flowing water from land now called San Pedro Valley.

INTRODUCTION AND OBJECTIVES

This project was designed to assess fluvial and geomorphic conditions of the lower 2.5 miles of San Pedro Creek that flows westerly to the Pacific Ocean through the 8.2 sq mi San Pedro Watershed (SPW) in Pacifica, California. His section of channel is referred to as the Study Site. Quantitative information on channel physical characteristics of the bed and banks was collected along this lower mainstem reach of San Pedro Creek during the summer and fall of 1999. Both the methodology and report emphasize the fluvial and geomorphic processes that have produced the present characteristics and conditions of the Study Site.

The report is presented in 5 main parts as the following section headings. First, a background of the Physical Setting is provided. Then, past conditions are explored through a Timeline. Next, a Field Analysis of channel characteristics and associated geomorphic processes is provided to document the status and condition of the channel. Together, the historical analysis and assessment of geomorphic processes lead to a brief discussion of the interactions of Land Use and Geomorphic Change. Finally, Recommendations for achieving long-term stream enhancement are included. The information provided by this project establishes baseline data that can be used to monitor change, identify and prioritize opportunities for restoration, and to potentially ameliorate some of the negative impacts of human activities on existing resources.

This report is not intended to serve as a sediment budget or an estimate of total, annual sediment load. Such a projection would require full-scale watershed analysis involving additional estimates of the sediment contribution from tributaries and hillsides, as well as the amount of sediment in storage and leaving the system. It does provide a detailed accounting of conditions during 1999 and the sources of sediment since the onset of nonnative land practices 217 years ago.

Specific information reported here for the length of the 2.5 mi Study Site, includes:

- length of stable, eroding and revetted stream banks;
- bankfull width;
- terrace heights, condition and type of bank revetments;

- natural and anthropogenic sources and volumes of sediment supplied to the channel;
- sediment size class distribution of the channel bed;
- estimates of bed incision;
- number, volume, location, and causes of pools of 1 ft or greater depth;
- pool spacing;
- amount, species and location of large woody debris (LWD);
- woody debris spacing, and processes associated with LWD recruitment; and
- reach classification (Rosgen, 1994).

Significant flooding last occurred in 1982 along the lower portion of the suburbanized San Pedro Valley. Consequently, the City of Pacifica is sponsoring a flood management project on the lower 3,100 linear feet of channel between the Highway 1 and Peralta Street bridges. The Army Corps of Engineers submitted a final Detailed Project Report in January 1998 (Army corps of Engineers, 1998). Groundbreaking for USACE Project began in year 2000 to reconstruct a meandering channel and floodplain that will support freshwater wetland habitat.

Resource values of concern to San Pedro Creek include its native steelhead fishery and other native fauna and flora that benefit from a contiguous riparian corridor. The San Pedro Creek Watershed Cooperative provided funding for this project as part of their community-based goals to find comprehensive solutions to protect and restore San Pedro Creek and the resources it supports.

PHYSICAL SETTING

TOPOGRAPHY

San Pedro Creek is a perennial stream that flows westward to the Pacific Ocean through the City of Pacifica, San Mateo County, California (Figure 1). SPW is located at the northern extent of the Santa Cruz Mountains. Its watershed boundary is shown as a red line. Montara Mountain, a prominent landmark forms the most southern extent of the SPW boundary. It has the highest relief in SPW, ranging from sea level to 1,898 ft at North Peak. Sweeney Ridge, forming the northern boundary, peaks at an elevation of 1,220 ft.

Hillsides to the south and east of San Pedro Valley are primarily open brush lands of the north coastal scrub assemblage. The hillsides to the north are composed of a mixture of grasslands, chaparral brush, and suburban development. Planted eucalyptus groves occur in various locations in the valley. As shown by the gray zone, the valley floor is almost entirely developed to the banks of San Pedro Creek.

Major alterations of the drainage network have taken place to increase tillable ground and ease access to crop fields. The timeline chronicles the most significant changes pertinent to landscape change and impacts. Most significant of changes was the lengthening of San Pedro Creek by putting it in an 0.8 mile-long drainage ditch to disconnect it from its former wetland and lake that was well upstream of the present outlet at the ocean shoreline. Presently, although San Pedro Creek still bypasses its small remnant of Lake Mathilda, it is undergoing reconstruction that involves a meandering channel and access of flood flows to a constructed inner floodplain.

Figure 1 1983 USGS Map of San Pedro Valley
Map too large to scan

~~letters~~ ~~send letters~~

There are at least 5 major tributaries to San Pedro Creek shown in Figure 1. They include Sanchez, South Fork, Middle Fork, North Fork, and an unnamed tributary to the southwest. The North Fo k, one of the larger tributaries to San Pedro Creek had at least 3.2 miles of it channel moved into a ditch at the valley side. Other channels were modified in this way as this was a common farming practice during the late nineteenth and early twentieth centuries. Following the 1950's, almost the entire ditched North Fork was placed into a culvert and buried to make way for suburban development. The watershed now has an estimated 13% of its area rendered impervious by constructed surfaces that are associated with urbanization (1998, EOA, Inc.).

CLIMATE AND STREAM FLOW

Climate of SPW is typified by a Mediterranean-type climate of dry, mild summers with coastal fog, and wet, cool winters. Mean annual precipitation has been previously reported as 25 in (Howard *ET al*, 1982). However, based upon new information from 13 rain gages around the watershed, USACE (1998) considers that normal annual precipitation is more likely 33 in for SPW, and that it ranges from 23 in at the Pacific Ocean to 38 in at the highest elevations. Rainfall records taken at the local San Pedro Valley Park gage for the last 21 years indicate an average of 38.2 in, see Figure 2. Intense rainfall of more than 0.25 in/hour have been documented in SPW on numerous occasions (Howard *ET al*, 1982). Microclimates within the watershed often maintain foggy cool weather at the coastal margin, and sunny hot weather at the inland headwaters. Stream flow through the mainstem Study Site and the major tributaries is perennial.

The table below lists drainage areas and bankfull discharges for the mainstem and its major tributaries. The bankfull discharges values are from published regional curves (Leopold, 1994). These estimates were developed for an average annual rainfall of 30 in for the San Francisco Bay Region.

Table of Watershed Drainage Areas

Watershed Name	Drainage Area (sq. mi.)	Distance Station at Confluence (ft)	Estimated Bankfull Discharge (Leopold, 1994)
San Pedro Creek at Highway 1	8.2	0	370
Unnamed Southwestern Tributary (Shamrock Cr.?)	0.6	3354	30
Sanchez at San Pedro confluence	0.9	7485	50
North Fork at Middle Fork confluence	2.4	11812	120
Middle Fork at North Fork confluence	2.4	11812	120
Middle Fork at South Fork confluence	1.3	13600	65
South Fork at Middle Fork	1.1	13600	57

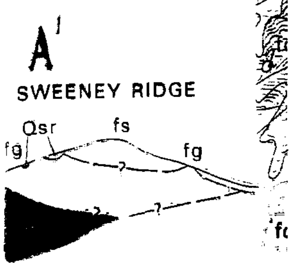
Coastal streams around the Bay Area typically have very flashy discharge. They may have little to no flow during the summer and very high short-lived discharges during storm events. Peak flows are directly influenced by drainage area, degree of antecedent rainfall, relief, vegetative cover, and amount of rainfall. Soils in the Bay Area may take about 9 in of seasonal rainfall before they become saturated (personal communication Ray Wilson, US Geological Survey). A discharge of 600 cfs is needed to produce flooding east of Highway 1 (USACE 1998). The Army Corps indicates that the flood of record, 1982 had an estimated discharge of 2890 cfs. Although there has been no long-term USGS stream gage located on San Pedro Creek, the USACE derived different flood recurrence intervals for the 10, 50, and 100-year floods by assessing discharge records of other similar nearby watersheds. They report approximately 1900 cfs, 3000 cfs, and 3450 cfs, respectively. These estimates seem high for the size of the watershed, but if they are reasonably correct, they might reflect the expected higher peak discharges associated with urban influences such as impervious surfaces, storm drains, road gutters, and channelized concrete streams.

GEOLOGY

A geologic map from Pampayen (1994) is shown in Fi[illegible]. The map shows discrete points of shallow landslides that were evident in 1968 [illegible]aphs. Many more are reported to exist than are shown. Howard *et al* (19[illegible] ma[illegible] the landslides as of 1982, but their base map does not have the geologic [illegible]ently interpreted by Pampayen.

SPW is characterized by alternating, sheared units of [illegible]es trending beds of the Jurassic/Cretaceous Franciscan formation that is faulted against Tertiary sedimentary rocks, that are in turn, faulted against Cretaceous granitic rocks at the southernmost ridge top. The two faults dividing these units are the right lateral Pilarcitos fault that dissects the valley floor and the normal San Pedro Mountain fault that trends along the southern ridge. The latter fault moves granitic rocks upward relative to downward movement of the sedimentary rocks of the north. Most of the other faults along the northern half of the valley are unnamed and they trend nearly parallel to the latter named faults. The northwest trending San Andreas fault is located northeast of SPW. Most of the other faults within SPW that exhibit lateral motion probably splay from the San Andreas fault. In the event of major quakes on the San Andreas, shear stress and potential offsets could distribute to these subsidiary faults. At present, however, Pampayen (1994) quotes the California Division of Mines and Geology (1982) that they do not consider the Pilarcitos Fault as active. Yet, Pampayen also states that he considers that it may be seismically active based on clusters of seismic activity south of SPW in Portola Valley and near Montara Mountain.

According to Pampayen, the predominantly Franciscan rock north of the Pilarcitos fault includes sandstone, diabase, greenstone, serpentinite, chert, and limestone. In some areas, these rocks are highly sheared to form melange. The Tertiary sedimentary rocks include sandstones, shale, and conglomerates. The granitic rocks of Montara Mountain are pervasively fractured and commonly weathered to 100 ft. The hills on both sides of the valley are mantled by residual soil and colluvium, which is often thickest within the zero-order basins at the heads of first-order channels. The valley bottom is filled with Quaternary-aged alluvium. Artificial fill is often present in many of the developed valleys. Wind blown sand and beach deposits exist along the western margin of SPW.



Pampayen, 1994.

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Geologic Bedrock Descriptions from E.H. Pampayen (1994)

Qya-	Holocene-aged younger Alluvium that is poorly sorted gravel, sand silt, clay and organic matter in active . modern drainage channels and small fans.
Qam -	Holocene-aged, medium grained alluvium that is unconsolidated to mediumly consolidated, moderately sorted sand and silty to clayey sand chiefly forming alluvial plains.
Qac -	Holocene-aged, coarse grained alluvium that is unconsolidated moderately sorted sand and gravel forming stream levees.
Qsr -	Holocene-aged slope wash, ravine fill, and colluvium that is unconsolidated to moderately consolidated deposits of sand, silt, clay and rock fragments accumulated by slow downslope movement of weathered rock debris and soil
Qb -	Holocene-aged, beach deposits that are loose clastic deposits composed of sand to cobble-size fragments in the tidal zone.
Qyl -	Holocene-aged younger landslides deposits that are unconsolidated to moderately consolidated deposits whose composition and structure depend upon bedrock geologic unit involved and type of landslide.
Qf1 -	Holocene-aged artificial fill that is poorly consolidated to well-consolidated gravel, sand, silt, and rock fragments in various combinations used in a variety of applications.
Qol –	Holocene to Peistocene-aged older landslide deposits that are moderately to well-consolidated deposits whose composition and structure depends upon the geologic unit involved and type of landslide.
Tsu -	Paleocene – aged predominantly very well indurated, soft to hard, light gray to brown, fine-0 to coarse-grained sandstone and pebble to cobble conglomerate, with lesser amounts of conglomeratic sandstone, siltstone, claystone, and carbonate beds, all containing granitic debris.
Tsl -	Paleocene – aged predominantly laminated to rhythmically bedded, soft to medium hard, brown, fine to coarse-grained, thin-bedded, arkosic turbidite sandstone and black shale.
Km -	Cretaceous – aged granitic raock of Monatara mountain that is pervasively fractures, punky, medium crystalline granitic rock, ranging from largely tonalite to granite and containing abundant hornblende and biotite.
fu -	Undivided.Cretaceous and Jurassic-aged meta-igneous and metasedimentary rocks.
fs -	Cretaceous and Jurassic-aged sandstone that is medium to coarse-grained, poorly sorted and locally tuffaceous with interbedded siltstone, shlae and sparse coal.
fcg -	Cretaceous and Jurassic-aged conglomerate that is well-consolidated, medium-hard, moderate-brown, with well –rounded pebbles to cobbles.
fg -	Cretaceous and Jurassic-aged Greenstone that is dark green to red, altered basaltic volcanic rock that includes pillow lava, breccia, tuff and minor related intrusive rock.
fl -	Cretaceous and Jurassic-aged limestone that is light gray, hard, dense, and finely chrystaline that contains thin interbeds and lenses of black chert.
Fsr -	Cretaceous and Jurassic-aged sheared rock that is predominantly soft, light- to dark-gray sheared shale, siltstone, and graywacke containing various-size tectonic inclusions of Franciscan rock type.

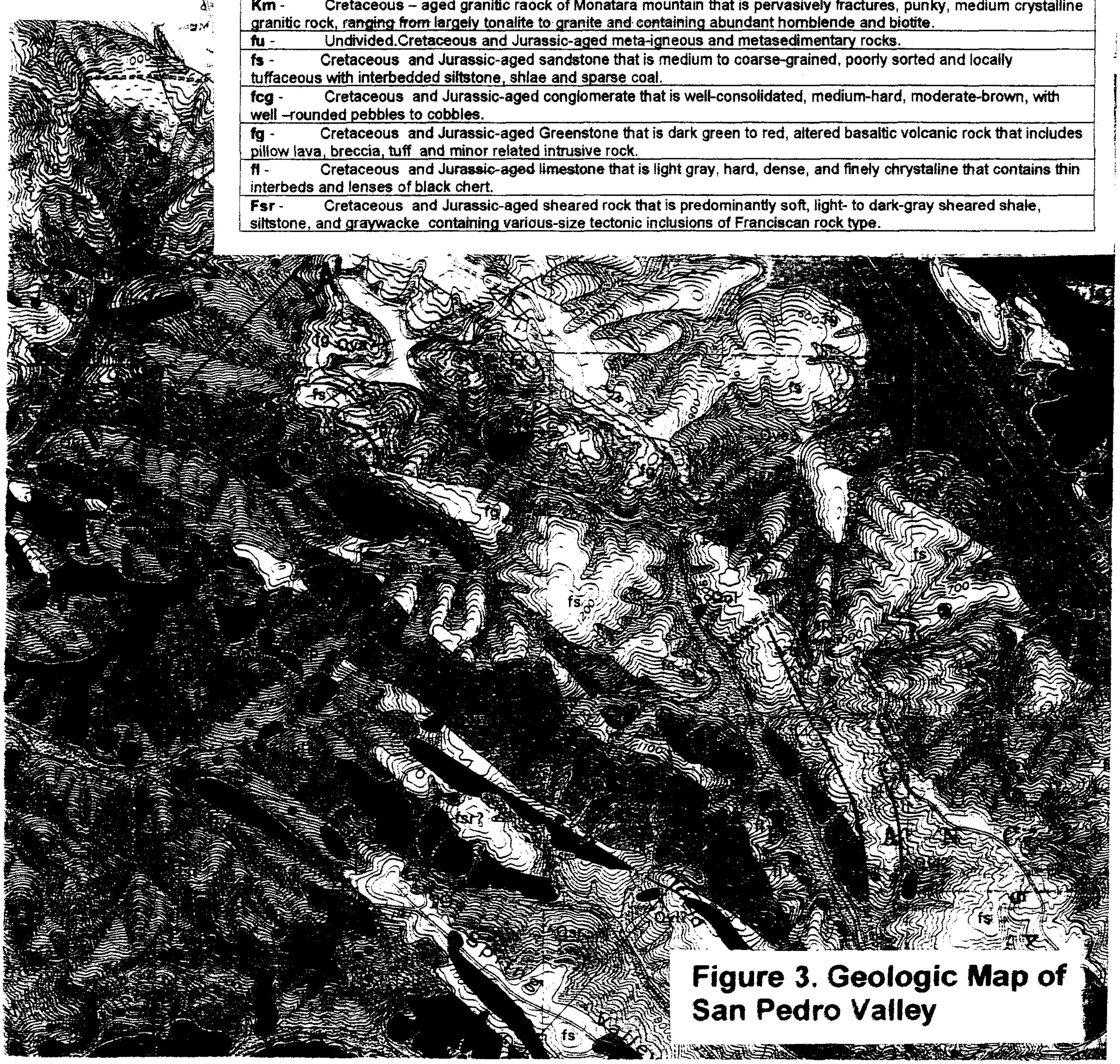

Figure 3. Geologic Map of San Pedro Valley

TIMELINE OF LANDSCAPE CHANGE

The following timeline provides a snapshot of different events that happened in or around San Pedro Valley that contributed to its present state. The timeline is not by any means an exhaustive survey. Readers with specific knowledge of events that influenced landscape change are welcome to add pertinent information to the timeline by emailing the authors at laurel@sfei.org.

To determine rates of change a timeline must be developed to determine when the SPW started responding to land use activities practiced by non-native settlers. Based upon the information provided below we have estimated that the landscape started responding to land use impacts by 1782. Recognizable disturbances from different land use activities have caused punctuated of periods of instability during the 217 years that San Pedro Creek has been adjusting to non-native settlement.

Past ~ 5000 years to early 16th Century Native people are living in the coastal landscape of Central California. By the 16th century about 275-350 native individuals are estimated to have lived along the coast between Montara Mountain and Half Moon Bay (Miller, 1971). One village, called Pruristac (Biosystems, 1991), is documented for San Pedro Valley. The Ohlone people actively and inadvertently manage the landscape by harvesting plants for food, baskets, boats, and clothing. They burn the landscape for hunting and forage at frequencies exceeding that of natural lightning strikes. They collect bulbs, seeds, and hunt fish and game that live about the watershed. Distribution and health of the native bunch grasses and chaparral plant communities were probably influenced by the land use practices of these people. The grasslands in San Pedro would have been mostly perennial bunch grasses, dominated by wild rye, junegrass, pine bluegrass, and deer grass (Burcham 1957 in Culp, 1999). Elk herds may have grazed upon moist meadow grasses growing adjacent to the riparian corridor of San Pedro Creek. It is not known for this time whether San Pedro Creek flowed freely to the ocean through a marsh, was captured by an upland thicket of willows, or flowed into a lake even larger than Lake Mathilda was in 1853. Similarly, it is not known whether San Pedro Creek was periodically separated from the Pacific Ocean by a sand spit that was constantly being built and cut away by wave action, or by sand dunes that were continually being modified by onshore winds. The creek may also have been permanently separated from the ocean except during extreme floods that could break a direct opening across the dunes. The presence of a native steelhead fishery indicates that, at least at times, San Pedro Creek connected to the ocean, perhaps during large storms.

1769, Oct San Pedro Valley is first viewed by Europeans. Miquel Costanso, a member of Captain Gaspar de Portola's expedition from Spain to find Monterey Bay, records on October 31st that "We went down to the harbor and set up camp a short way from the shore, (in a lush little valley) close to a stream of running water which sank into the ground turning into a marsh of considerable extent (covered with cane grass) and reaching near the sea. The country was plentiful in grass, and all surrounded by very large hills making a deep hollow open only toward the bay of the north west" (from Costanso in Stanger and Brown, 1969; and Biosystems, 1991).

Padre Crespi, another member of the expedition, recorded that "The valley has a great deal of reed grass and many blackberries and roses; there are a few trees in the beds of the arroyos, and some moderate-sized willows, but on the hills there was not a single tree to be seen except on a mountain range that encircles the bay. Not far from the bay we found a village of friendly heathen, who, as soon as we arrived, came to visit us with their present of tamales made of black seed" (from Palou, 1926, in Biosystems, 1991).

1769, Nov Captain Gaspar de Portola's expedition views the San Francisco Bay from Sweeney Ridge (Stanger 1963). They camp in San Pedro Valley at an Ohlone village site. They observe frequent fires set by native people in the Bay Area landscape (Miller, 1971).

1774 Rivera-Palou expedition visits San Pedro Valley. Padre Palou recorded that "At eleven we came to a large lake between high hills, which are in the plain ending in a small bay on the beach, about a league distant from Point Angel de la Guarda. If the beach permits it and there is no precipice in the way, we will save a good stretch of road and avoid some bad spots. The lake compelled us to make detour of about half a league, and it was necessary for us to draw close to the beach and cross over the sand which surrounded the lake. We made a detour around the lake and stopped about one in the afternoon in a canyon of the valley near an arroyo of running water, one of the two in the valley from which the lake is formed. It is well covered with tule, and on its banks, there are some willows and blackberry brambles. The beds of both arroyos are the same, and on the slopes of the hills, I saw here and there a live oak. If the place had timber it would be suitable for a mission, on account of its proximity to the mouth of a port, for it does not lack land, water, or pasture for cattle" (From Palou, 1926, in Biosystems, 1991).

1776, Jun Anza's party of 240 men, women, and children with hundreds of mules and horses and some 300 cattle, leave Monterey for the founding of San Francisco's Mission Delores and Presidio (Stanger, 1963). The cattle belonged to both entities of church and government. Notably this is just a few days after the signing of the Declaration of Independence at the eastern continental coast.

1779-1786 Dietz (1979, in Biosystems 1991) reports that 35 people from Pruristac, including 8 men, 9 women and 18 children, are converted to Catholicism.

1782, Dec Because San Pedro Valley has more sunshine and good soil to grow crops and grasses to support cattle, an outpost for Mission Delores is soon established in San Pedro Valley (Palou and Cambon, 1782, in Biosystems, 1991). Biosystems reports that it was situated at the same location as the Ohlone village that Portola had visited while he camped along San Pedro Creek. Early structures were probably built with wooden poles plastered with mud and roofed with thatch (Culp, 1999).

1786 A granary, chapel, and drainage ditches are constructed of adobe by the Fathers at the San Pedro Mission Outpost. Stream or beach cobble, and limestone is used to line the ditches. The land is plowed. Two ditches were constructed to "direct the water" while others were "opened to drain the water which spread on the field" (Dietz, 1979). Very soon, the Padres reported that all of the Mission's plantings were transferred to San Pedro.

1787, June A ditch 5,643 feet-long was opened along a planted hedgerow of willows to provide irrigation for the "willow fence," vineyard, and crops of wheat and corn (Stanger, 1963), (Dietz, 1979). About 90 acres of field were cleared for crops (Chavez, Dietz and Jackson 1974, in Culp, 1999). Commonly, the Padres reported damaged crops by local grizzly bears.

1788 Padres Benito and Garci report plantings and harvest of wheat, barley, peas, broad beans, kidney, beans, lentils, and corn in San Pedro Valley. They write that water ditches are being cleaned out and five bridges are being repaired (Dietz, 1979).

1790 Padres Cambon and Danti report that in the cultivated area of San Pedro and San Pablo a 1,375 ft-long, very deep and wide ditch was opened during the fall to drain the lands (Dietz, 1979). Milliken (in Dietz, 1979 from Biosystems, 1991) suggests as many as 300 [Indian] people were living in San Pedro. More deaths than births are reported for Ohlone people due to an epidemic of syphilis (Stanger, 1963).

Late 1700's through 1800's As the land became increasingly developed, and as the land use practices of the native people were abandoned, the frequency of anthropogenic burning practices decreased in San Pedro. At the same time, intense grazing pressure from cattle and sheep contributed to European annual grasses having a competitive advantage over native bunch grasses. The abundance and distribution of native perennials started to diminish. In addition, with reduced fire frequency, brush species started to have a competitive advantage over "annual" grasses. Yet, the effects of heavy grazing kept brush invasion down to low levels.

1791 Padres report that they are concerned about the amount of space on the San Francisco peninsula because the cattle that the church administered increased from less than 200 head to nearly 1800. With horses, mules and sheep, the number of animals totals 3,600. During the same fourteen years, the Presidio's herd grew from 115 to 1215 (Stanger, 1963). Orders came from Mexico that the cattle at Rancho del Rey (eastern San Mateo County) were to be driven to Monterey and added to the King's herd. This established that the missions were to sell the cattle to the army men, putting the Government in a position of dependence upon Mission Delores.

1792 Epidemics from which the Ohlone people had no immunity caused 50 deaths at the San Pedro Mission Outpost. Normally only about a dozen deaths per year occurred (Biosystems, 1991). Baptisms dropped to almost none, probably indicating drops in native births and population in SPW, as well as distrust and alienation of any remaining native people toward the mission.

1793 Despite the apparent loss of population, the Outpost remains an important source of food for Mission Dolores, without which it would be impossible for the Missions to exist (Biosystems, 1991).

1794 Almost nothing is reported in the mission diaries about San Pedro Mission Outpost. The adobe buildings slowly crumble and all that remains is a cemetery, cattle roaming the hills, and possibly a little absentee farming (Stanger, 1963).

1795 to early 1800's The human and economic loss at San Pedro turned the missionaries to the eastern side of San Mateo, where during peak years of prosperity as many as 10,740 cattle were pastured in various areas. It is probable that the pasturage included SPW. As many as 10,000 sheep, hundreds of horses and mules are reported for San Mateo County (Stanger, 1963).

1796 Governor Diego Borico was persuaded to reestablish Rancho del Rey and ordered 265 head of cattle to be purchased from Mission Dolores. He further announced that the region known as Buri Buri would be taken by the Presidio for its grazing lands and that the Mission could continue to graze in six other food pasturing areas. Among them was San Pedro (Stanger, 1963).

1798 Josef Arquello reports in a U.S. Court land case that there are various herds of large livestock in San Pedro (Biosystems, 1991). It is also noted that the grass stays green year round at San Pedro.

1800 Padre Landeata wrote in 1800 (Biosystems, 1991) that 6000 head of sheep were at the Outpost and 20 cows are killed each week, but there are many. Biosystems reports that references to San Pedro are rare following this time

1804-7 An epidemic of measles further reduces the population of Ohlone people associated with the missions (Stanger, 1963).

1812 Record crops are harvested in areas along the peninsula (Stanger, 1963).

1821 Mexico achieves independence from Spain and financial support to the missions is cut off. The number of neophytes in Mission Delores drops from 1,100 to less than 200, where it leveled-off for a decade (Stanger, 1963).

1822-1846 The major industry of ranchos throughout California, including San Pedro, is the production of hides, tallow, and wool. Rodeos were held once a year where the cattle were concentrated into small areas and branded.

1828 An 1828 census taken by the military commander of the Presidio includes a notation of "rancho San Pedro to the southwest 7 leagues for livestock and crops" with 26 Indian men, women and children living there (Biosystems, 1991).

1835 Mission Delores is secularized, mission control over Costaños people is abolished, and mission properties are taken over by the Mexican Government. José Sánchez receives title to Rancho Buri Buri and has at least 2,000 cattle and 250 horses at the time. Sánchez's son, Francisco, receives title to 8,926 acres of Rancho San Pedro including the ruins of the mission outpost. Francisco builds his new home at the outpost site from adobe bricks that the Mission converts had made (Stanger, 1963). The number of livestock owned or given to Francisco is not reported. It is likely that his father's herd grazed within SPW, since fence lines were still not a common part of the landscape. The inventory of mission property at the time indicates 4,109 head of cattle, 87 horses, and 5 burros (La Peninsula 1961, in Culp, 1999). When Sánchez built his adobe, the creek meandered "a few feet" below ground level according to Drake (1952, from Culp, 1999).

The Barcena Diseño of 1835 is shown in Figure 4. It is after Brown (1957) from Dietz (1979). The map shows San Pedro Creek flowing through a willow thicket, otherwise referred to as a sausal, to Lake Mathilda near the ocean shoreline. The Sausal is shown to extend into the lake at its southern edge. This indicates that the lake may have had freshwater to maintain the willows. The creek is shown as a single channel. The location

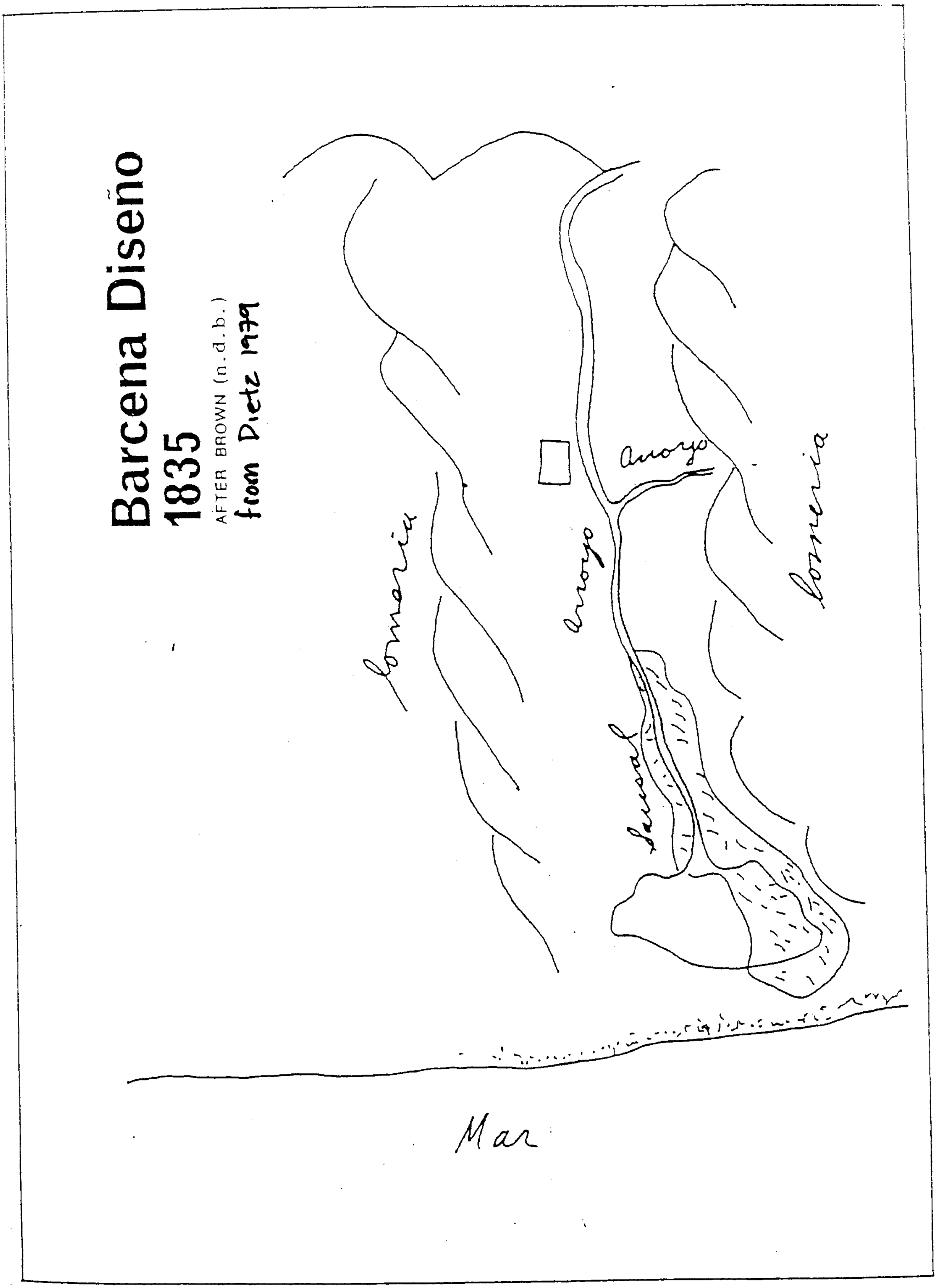

Figure 4. 1835 Barceno Diseño

of the Adobe is shown as rectangle. The lake is not shown to have an ocean outlet. This map was drawn by memory, so the relationship between creek and wetland features is inferred but not firmly established.

1838 The DeHaro Diseño (1838) from Dietz (1979), Figure 5 shows San Pedro Creek flowing to a sausal which is drawn distinctly separate from a wetland feature surrounding a lake or laguna {Lake Mathilda} near the shoreline. A channel is not indicated in the sausal nor is there shown an ocean outlet for the lake. Although these maps were drawn only by memory, yet the similarity of some of the interpretations is notable.

1841 Congress passes a law allowing frontier settlers to file claim to not more than 160 acres of government land that had not been surveyed, which gave the settlers first right to claim the land when it went on the market.

1849 Gold rush hits California and population of San Francisco Peninsula start to increase rapidly.

1850 California is incorporated into the Union, therefore Mexican landowners had to prove their ownership of land.

1853 San Pedro Creek is mapped by the U.S. Coast Survey, Figure 6, as draining into a sausal just slightly downstream of the Sanchez Adobe site. The sausal ends just short of Lake Mathilda that existed between the beach sands of the ocean and the seasonally wet and/or sandy soils surrounding the sausal. We consider that it is possible that San Pedro Creek separated into several distributaries beneath the sausal forming a seasonal fresh water wetland upstream of Lake Mathilda. No channel is shown to flow through the willow thicket to the lake. It may have started to become partially saline from ocean water seeping through beach sands at its southern shore near the ocean. Recall that this was the general area where willows had been shown in the 1835 map (Figure 4). On the north side of the watershed, near a rectangular shape demarcating a coral, there is channel that has been mapped as a gully feature. This is in the same location as the prominent gullies that are apparent on the hillsides today.

1859 The last sighting of a grizzly bear in SPW is reported (Hynding, 1982).

1860 Census listed only 62 persons on the Peninsula as Indian born in California.

1862 Francisco Sanchez dies and Rancho San Pedro is divided up among several San Francisco financiers and land speculators (Culp, 1999). Land holdings are subdivided into long, narrow north-south-trending plots and leased to dairy ranchers and farmers.

1866 Figure 7 shows an 1866 depiction of San Pedro Creek that is very similar to the 1853 map and probably derived from it. The map is on file at the Sanchez Adobe Historical Museum. It shows more of the southern portion of the watershed and depicts the Indian trail and coast road that travels over San Pedro Mountain. It designates much of the lower San Pedro Valley as Market Gardens.

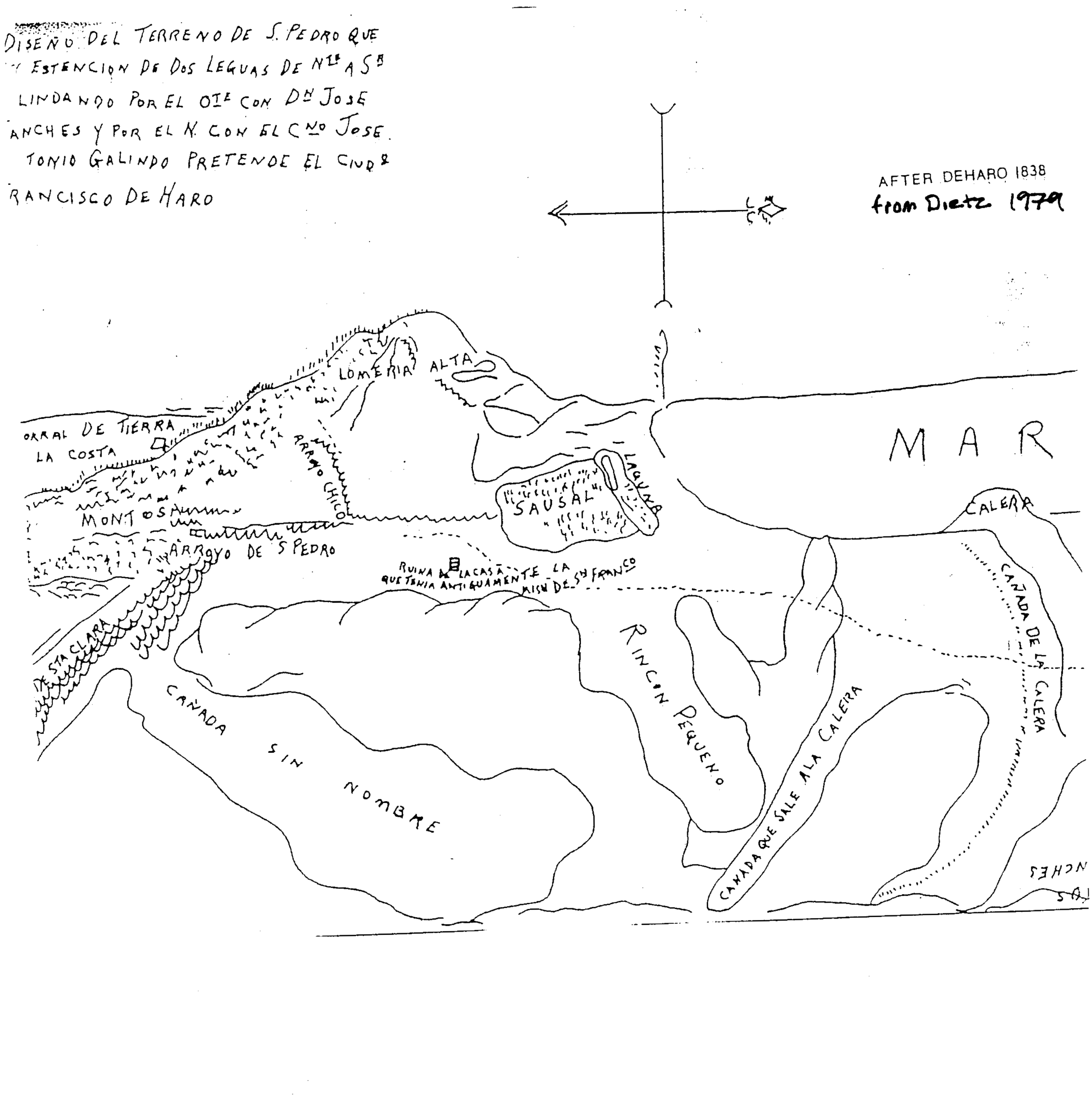

Figure 5. 1838 DiHaro Diseño

1868 Figure 8 shows San Pedro Valley in a map after Easton in Dietz's Archeological Investigation (1979). San Pedro Creek is now shown as a single thread channel flowing through the willow grove directly to the ocean shore. Lake Mathilda is shown to have a drainage outlet that connects to San Pedro Creek. Whether this is a reasonable depiction of the relationship between the wetland and creek features cannot be definitively determined, although it is possible that this maps depicts when San Pedro creek was ditched to drain more of the valley. The fact that a small willow grove is still present may indicate that the valley is not yet drained or arable.

Mid – late 1800's The earliest eucalyptus were brought to the Bay Area in 1853 (Culp, 1999). In San Pedro, blue gum eucalyptus, Monterey pine, and cypress were planted in groves. Eucalyptus groves started to dominate portions of the hillsides such as the south western slopes where San Pedro Valley Park now exists. The exact date of their planting in San Pedro has not been determined. Examination of historical photographs of the turn of the century shows well established trees, indicating that they may date back to the 1880's.

1870's This seems to be a reasonable estimate for the approximate time period by which portions of San Pedro Creek and some of its tributaries were diverted into ditches. For San Pedro Creek, the ditch was excavated from just east of the Adobe building all the way to the Pacific Ocean. Whatever former channel existed, it was plowed over and planted with crops. This is likely the time that a large portion of the North Fork was straightened and ditched as can be seen in the circa 1928 photograph (Figure 11).

1890 Dante Dianda of Granada, just south of San Pedro, is the first to grow commercial artichokes along the coast (Culp, 1999). Artichoke production in San Pedro Valley probably followed shortly. Frequent flood irrigation during the summer was required in the early years and metal pipes were used to divert water from the creeks for artichoke irrigation (Culp, 1999).

1894 Figure 9 shows an 1894 parcel map after Bromfield in Dietz's Archeological Investigation (1979). San Pedro Creek is shown to flow into Lake Mathilda, which has an outlet to the Pacific Ocean. Whether this is a reasonable depiction of the relationship between the wetland and creek features cannot be firmly established. The map shows parcel boundaries, the creek network and a road system. It does not depict the willow thicket. It is plausible that San Pedro Creek was ditched some time before this map was made. The position of the unnamed creek just to the west of Sanchez Creek follows the same planform of the ditch that shows up clearly in the 1928 photo in Figure 11.

Mid 1800's to mid 1900's Immigrants settle into San Mateo County and truck farming begins. Irish farmers move to San Pedro Valley where they grow crops of potatoes, cabbage, and grains (Savage 1983, in Culp, 1999). Oats and barley are proven to grow better than wheat in the cool coastal climate (Culp, 1999). The residual straw following harvest of oats was left in the fields to dry over the summer and then would be burned in fall, sending thick clouds of smoke over the farms (Miller, 1971). The cool climate eventually doomed potatoes and wheat as cash crops (Savage, 1983). Culp (1999) states that Italian farmers introduced new crops to replace the failing potato, which

Figure 6. 1853 US Coast Survey Map of San Pedro Valley

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Figure 7. 1866 Modified US Coast Survey Map of San Pedro Valley

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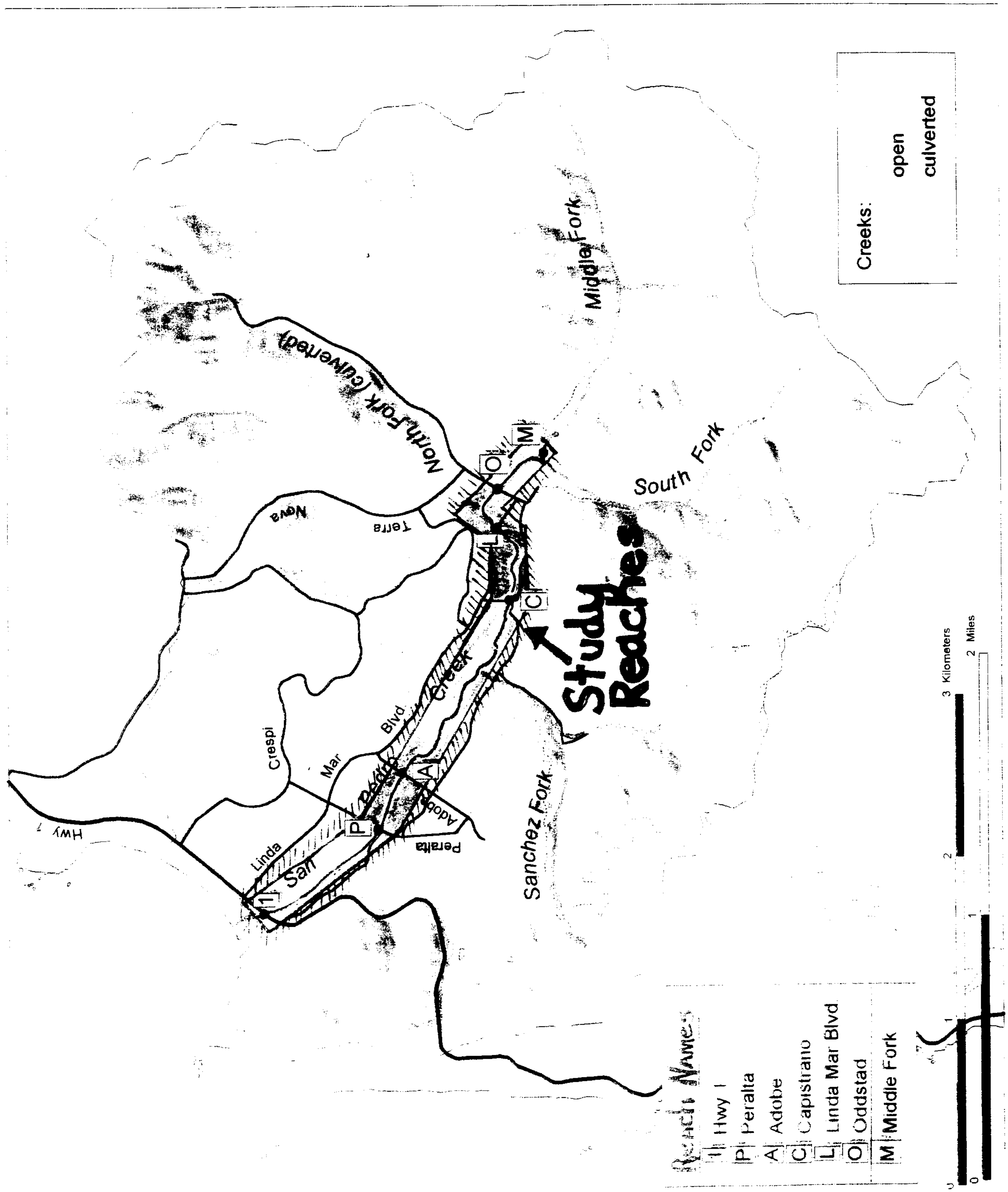

Figure 14. San Pedro Creek Study Reaches

actually be functioning as a barrier. Furthermore during high flows, the concrete-walled ditch upstream is probably quite challenging for fish to migrate through because of high water velocities and no significant resting areas over its 640 ft length. The year that this section of channel was originally ditched is not presently known, but it may have been originally modified during the farming era of the late 1800's.

1972 Flooding is reported in Pacifica (Pacifica Tribune, 1995)

1982, Jan Flooding is reported in Pacifica (Pacifica Tribune, 1995). During the Storm of Jan 3-5, about 6 to 8 inches of rain fell in less than 30 hours. Rainfall intensity reached 0.25 in/hr. At least 475 landslides took place in Pacifica (Howard and Baldwin, 1982). Loss of life and extensive property damage occurred in San Pedro Valley because of debris flows that were initiated at the heads of first order channels on slopes of 26 - 45 degrees. Nearly all the debris flows were in soils less than 10 ft deep, but the combination of their long runout lengths below and urban development at the base of the runout pathways proved to be devastating. Two deaths occurred along Oddstad Blvd from a single debris flow.

1988 U.S. Army corps completes a Section 14 Levee Protection Project along the north bank of San Pedro Creek between Highway 1 and Pacific Ocean. The levees were built to protect Linda Mar Sanitary Sewer Pump Station (USACE, 2000).

1993 A 1993 USGS map, Figure 1, shows that more development and culverting of tributaries had occurred up the valleys of the North Fork.

2000 The current population of San Pedro Creek is 39,080. The principal land use is suburban development. No large industries exist. Recreational open-space areas are located along the western beachfront and the southern and eastern hillsides. There is no agricultural farming, few cattle are present, although there are a few horse stables. The USACE (1997) reports that stream bank overflow of the terrace banks of the valley floor occur during events with less than a 4-year recurrence interval. Vegetation clearing, bank protection and stabilization within San Pedro Creek is managed by the City of Pacifica (USACE, 1997). The South Fork is a water source for the City of Pacifica and provides 10% of the City's drinking water (San Mateo County Parks and Recreations Division, no date). The extent of grasslands has diminished, partly from development and partly from brush encroachment from the lack of fire management and grazing activities. Grassland composition is predominated by European annual grasses and invasive weedy species. Many nonnative trees grow on the hillsides; most are either eucalyptus, Monterey Pines or ornamentals. Nearly all of Lake Mathilda has been filled except for a small portion behind a shopping mall. The native steelhead fishery has drastically diminished. The USACE has started a Flood Control Project that involves construction of a bypass channel downstream of Peralta Road.

FIELD ANALYSIS OF CHANNEL CHARACTERISTICS

STUDY AREA

The study site, shown in Figure 14, extends 2.6 miles along San Pedro Creek from its uppermost extent of extreme tidal influences, near the downstream edge of Highway 1 Bridge, to the confluence of the Middle and South Forks. The Study Site is divided into distinct reaches defined at their downstream end points by box culverts or bridges. The table below describes the reach names, their lengths in feet, and distances upstream from distance station zero that corresponded to the downstream edge of San Pedro venue Bridge. A fiberglass tape was pulled in the field along the centerline of the channel to determine the distance stations.

Table of Channel Reaches for San Pedro Creek

Reach Name	Length of Reach (ft)	Distance from Station Zero at Hwy 1 (ft)
Highway 1	3,110	3,110
Peralta	1,264	4,374
Adobe	5,017	9,391
Linda Mar	1,910	11,301
Capistrano	1,275	12,576
Oddstad	1,217	13,793

Figures 15a-15c, show Photo Base Maps of the Study Site that depicts an expanded view of the reaches, and includes the distance stations locations at 300 ft intervals, and street names at bridge crossings. The base maps are orthorectified photos taken on the 8th of August, 1995, for the County of San Mateo. Their scale is 1:4800 where 1 inch equals 400 feet.

While viewing the pages, it is worth noting the straightness of the channel downstream of Adobe Bridge where San Pedro Creek has been diverted into a man-made ditch. Also, note the change in size and abundance of riparian vegetation.

METHODOLOGY

A very brief discussion of methods follows. Further description of some of the methods follows in the subheadings discussed for the different channel characteristics.

As the centerline tape was pulled continuously along the channel, all data were referenced to distance stations along the tape. Flagging, annotated with distance stations, was tied every 300 ft. These distance stations, when combined with the Photo Map, could be used to revisit the same stations during future monitoring. The distances of engineered structures such as bridges and culverts were noted and can be used to match distance stations in the future.

Telescoping survey rods were used to measure bankfull width, height of terraces, and heights and depths of bank and terrace erosion. Bank measurements were separated into sections below and above bankfull height, which, in concept, is equivalent to the height of the floodplain. Bankfull discharge occurs every 1.3 to 1.7 years on average and is regarded as the channel-forming flow that maintains the hydraulic geometry of the channel to move the most water and sediment over time. The threshold for measuring bank erosion was at least 1/4 ft retreat for the overall height of the bank. If there was a landslide scar, we attempted to reconstruct the shape of the slope to determine how much sediment was supplied to the channel.

The threshold for measuring whether sediment was supplied to a stream was that the erosional feature could not be older than 217 years, which was the time that we determined that non-native land use activities influenced SPW. Trees that had their roots exposed along eroding banks or that were growing in landslide scars were dated using an increment borer and establishing a diameter age relationship for the different species.

Level-line surveying methods were used to measure cross sections that helped determine bankfull height. Standard sieve sizes were used to establish sediment size classes to characterize the channel bed into "D50" size classes, where 50% of the particles are either finer or equal to this size category.

All pools greater or equal to 1 ft deep were measured and documented at the time of initial data collection. Pool depths were determined for potential conditions of minimum flow by subtracting the height of the water at the crest of pool tails. Pool volumes were determined by multiplying average width x length x 1/2 maximum depth. The width and length measured in the field accounted for potential minimum flow.

Photographs of the channel were taken at places of obvious changes in channel conditions. Photographs were referenced to distance stations, placed in a notebook, and arranged from downstream to upstream order.

Data were entered in field books and were later entered into data templates linked to analytical and graphics programs to calculate or display the desired stream parameters. The raw data and channel photographs are on file with the authors.

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~~Step 4 of 5~~

Figure 15a. 1995 Photo Base Map

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Figure 15b. 1995 Photo Base Map

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Figure 15c. 1995 Photo Base Map

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The Longitudinal Profile

The energy slope of a stream is approximated by its gradient. Gradient depends upon discharge, bed-material size, and load. The gradient for different reaches of San Pedro Creek in Figure 16 are derived from data from the USACE (1998) downstream of Adobe Bridge and from USGS 7.5' quadrangle upstream of Adobe Bridge. Individual reaches within the Study Site are shown in color and the downstream edge of bridges is shown with black arrows. The reported percent slopes are based upon the end point elevations within each reach. Channel distances approximate the distances measured in the field because the topographic map does not account for all the channel curvature. For accurate distances, refer to the Photo Map distance stations.

The reaches within the Study Site all occur within a morphologic zone referred to as the alluvial valley of San Pedro Creek. We have separated out the portion of San Pedro that was connected to a man-made ditch built to drain lower San Pedro Valley. Average stream gradients range from 0.44% at Highway 1 Reach to 1.62% at Linda Mar Reach. Linda Mar Reach is slightly steeper than the upstream Oddstad Reach. This is probably due to the effect of a slightly steep alluvial terrace face upstream of the North Fork where San Pedro Creek emerges from the narrower valley of the Middle Fork.

When viewing this graph keep in mind that it represents the elevations where the stream intersects a contour line on the USGS 7.5' quadrangle. It is not an accurate representation of the true channel bed elevations of modern San Pedro Creek. The historical profile would have ended shortly downstream of Adobe Bridge where stream flow submerged into a willow thicket upstream of Mathilda Lake. The historical elevation of the bed was higher, the channel was shorter, and the gradient must have been flatter than its present configuration.

SAN PEDRO CREEK LONGITUDINAL PROFILE WITH MORPHOLOGIC ZONES AND STREAM REACHES FOR 2.6 MI STUDY SITE

Elevations downstream of Adobe Bridge are derived from USACE 1998, while elvations upstream are derived from the 7.5' 1993 USGS Montara Mountain Quadrangle. Slopes are determined from end points elevations of each Reach.

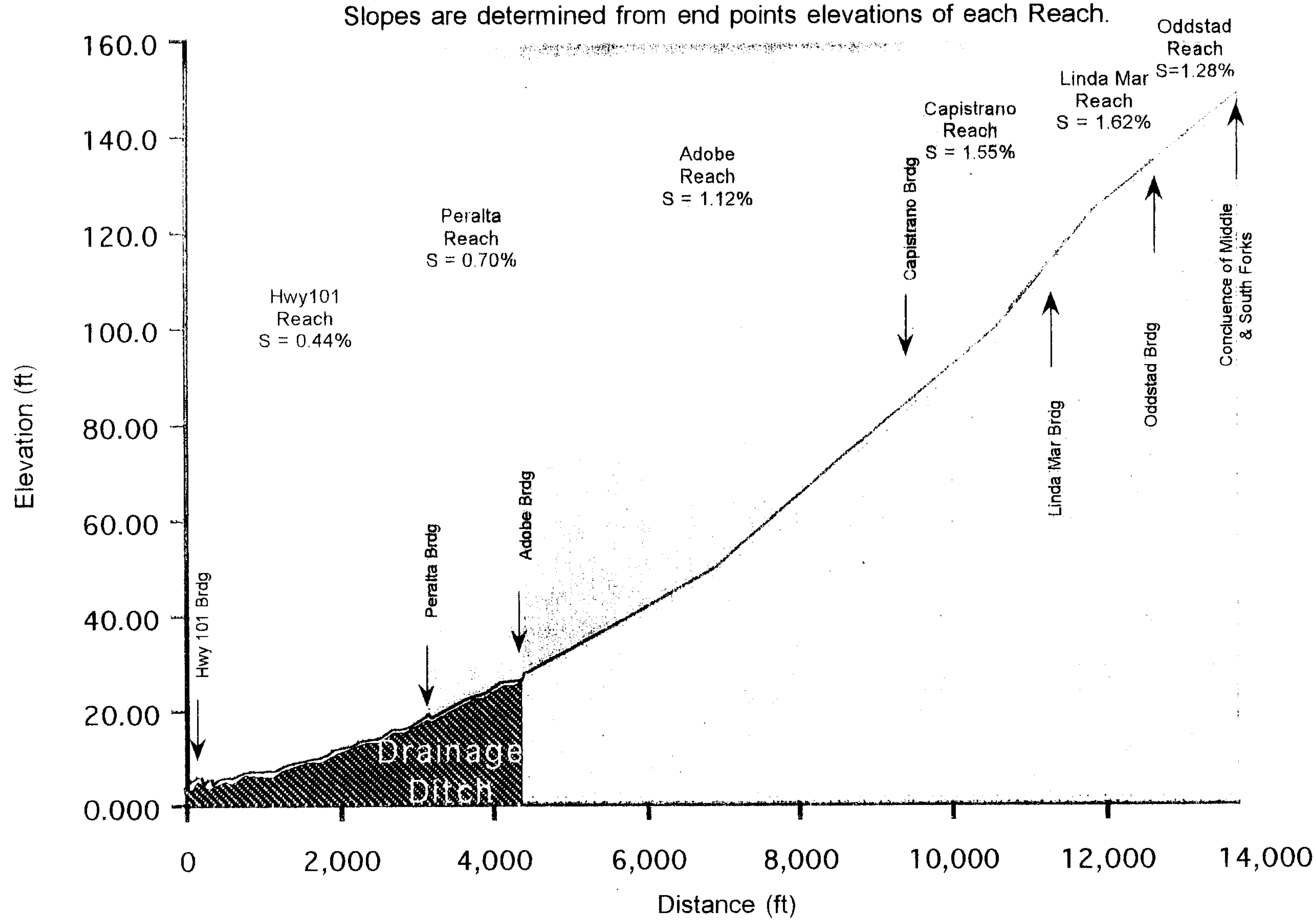


Figure 16. Morphologic Zones and Stream Reaches

STATUS AND CONDITION OF BANKS

The banks of a channel can be divided into two categories, either above or below bankfull flow. The bankfull channel is formed by flows that occur on average every 1.5 years and are often referred to as the channel forming flows. At bankfull elevation, a floodplain may exist. Banks above the floodplain or bankfull elevation are called terraces. Whether they are floodprone depends upon their elevation above bankfull. Banks below bankfull are subjected to flow more frequently, but their overall height and therefore contribution of sediment by erosional processes may not be as great as the contribution from terrace banks that can be tens of feet high. The condition and contribution of sediment from terraces and banks below bankfull were evaluated along the entire length of the Study Site.

Banks were quantified as eroding, revetted or stable. Bank erosion was only measured if there was at least 0.25 ft of retreat averaged over the entire bank and if the erosion occurred within the last 217 years. The latter was determined by assessing the freshness of the feature, aging or coring trees that had exposed roots, and reviewing historical photos and maps. Length and height of eroding banks were measured to determine the volume of sediment supplied to the channel. If a bank had some type of structural revetment, its length, type and condition was noted. If neither erosion nor revetment defined the bank condition, it was considered stable.

The location for each condition was documented by recording its distance station. The specific documentation can be viewed by looking at the Streamline Graphs, in the Appendix. The specific volume of sediment associated with each erosional feature is also shown on the Streamline Graphs.

Terrace Heights Relative to Thalweg

If the deepest part of the bed (thalweg) is used as the zero datum, terrace heights can be measured and plotted along a longitudinal continuum without having to survey in actual elevations. Changes in the height of the highest terrace relative to the thalweg are plotted in Figure 17 to show maximum relief along the channel length. This plot gives a visual perception of the degree of incision within the terrace banks ands helps illustrate where volume of sediment supply from terrace bank erosion might be greatest because of increased bank height. For San Pedro Creek, terrace heights tend to fluctuate but generally increase in height in the upstream direction. The channel becomes suddenly less incised at the Capistrano box culvert. This is because the difference in bed height between the upstream and downstream side of the box culvert is nearly 15 ft. The Capistrano structure includes a fish ladder and 640 ft of concrete-walled ditch upstream of the box culvert. We assume that at the time of construction, or perhaps from a much earlier bridge structure that was replaced, there was a headcut in the channel that caused such a difference in height. Although the present structure has prevented further incision upstream, its design probably inhibits fish passage and may have contributed to incision downstream.

The average topographic relief through the lower reaches appears to be about 9 ft. In the upstream reaches, it gets as high as 22 ft in some sections. Adobe and Linda Mar Reaches have the greatest relief between bed and high terrace banks. These are also the reaches with the greatest total volume of sediment supplied from bed incision and bank erosion, shown later in Figure 25.

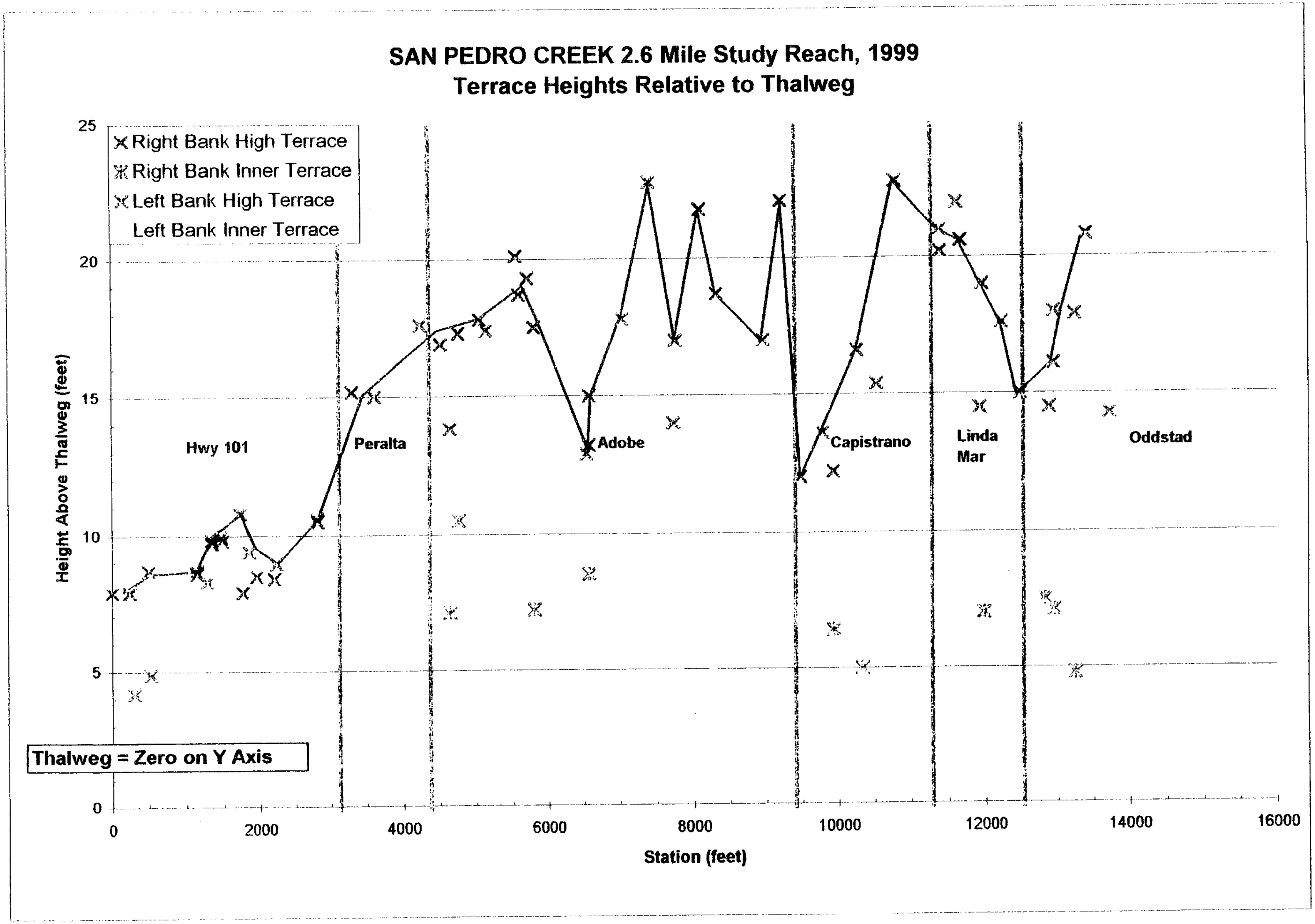


Figure 17. Terrace Heights Relative to Thalweg

Percent Length and Bank Conditions

These graphs in Figure 18 show the combined condition of banks above and below bankfull that have resulted from land use practices and natural rates of erosion during the last 217 years. There are two graphs. The graph on the left shows bank condition by reach. The graph on the right shows the summation of bank condition for the entire Study Site. The green color represents stable banks, the red-stippled pattern indicates eroding banks, and the gray diagonal pattern indicates revetted banks.

The graph on the right shows that 37% (1.9 mi) of the total length of both banks has eroded and supplied sediment to the channel. 43% of the bank is stable and 20% (1 mi) of it has structural revetment. Although a stable stream will clearly have some proportion of it's banks eroding over time, we consider that only 37% length for stable banks to be low and represents accelerated erosion rates of erosion from land use activities. It is noteworthy that only about 67% of the length of the Study Site is within its former channel position. The lower portion of San Pedro Creek, 33% (0.8 mi) of Study Site length, is in a drainage ditch. Only a small portion of the ditch length represents a pre-existing channel because San Pedro Creek used to disperse into a willow thicket that emerged into Lake Mathilda.

The graph on the left shows that Adobe Reach has the lowest percentage length of stable banks, only 30%. As the Photo Maps in Figure 15 showed, this section of channel is more sinuous than other reaches within the Study Site. It is also the first section of natural channel that occurs upstream of the drainage ditch. The three reaches upstream, Capistrano, Linda Mar, and Oddstad have a fairly consistent amount of stable banks ranging from 39% to 43%. The greatest length of revetment is in Capistrano Reach where 39% of its banks are artificially revetted. Adobe Reach has the greatest length of eroding banks, 53%.

Highway 1 Reach, which is within the drainage ditch, has the least length of eroding banks. We noticed that the ditch might have undergone a period of incision after it was first constructed, but now the ditch has inset banks that are well vegetated. The vegetation at the lowered bankfull elevation helps protect the banks from accelerated rates of erosion. Unfortunately, we do not have the original dimensions of the drainage ditch, so bank erosion measurements are our best estimate of sediment suuply based upon field evidence.

The graph on the right shows that 37% of the bank length is in an eroding condition. One of the objectives of these graphs is to put a perspective on the eroding banks. Preferably, this amount of eroding bank will not be converted to artificial revetment. From an ecological perspective, biotechnical stabilization would benefit the ecosystem much more than continued application of artificial materials, and could increase the amount of stable bank that has native riparian vegetation. An obvious goal is to convert eroding areas into stable banks that don't induce more erosion from instream structures.

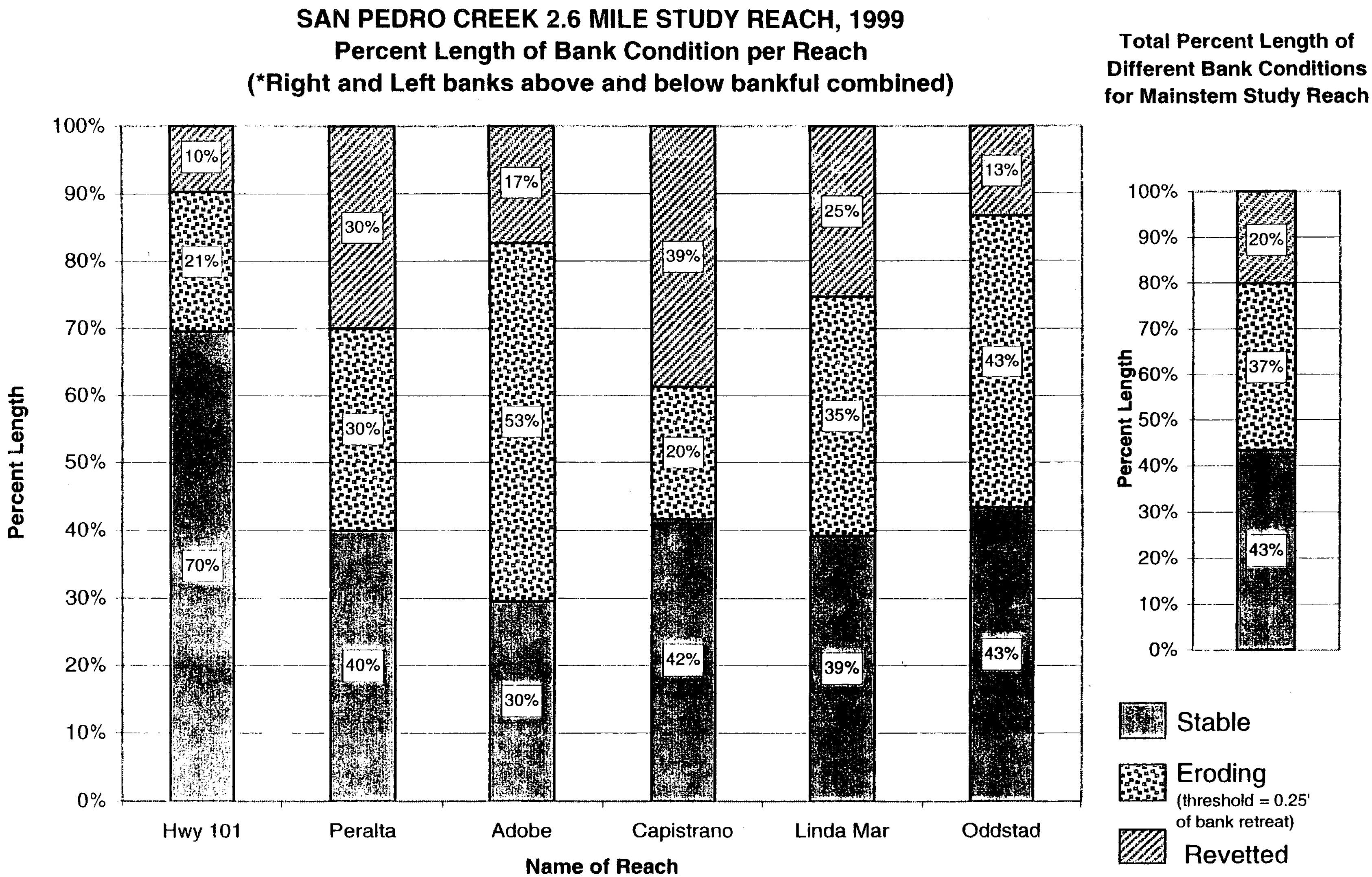


Figure 18. Percent Length of Bank Conditions

Mainstem Bankfull Width and Structures Crossing the Creek

Variations in bankfull width are shown in Figure 19 along the length of the Study Reach. Width ranges from a minimum of 11.5 ft to as wide as 40 ft. Bridge crossings are shown as red lines. Remnant flashdams and weirs are shown as blue lines. There are at least 10 such structures. The overall average bankfull width for the Study Site is 21 ft. Despite the input from tributaries, the variation in average width for reaches below Oddstad is very small. Oddstad Reach has less width because it is upstream of North Fork. Average reach values for bankfull are shown in the table below.

Table of Average Bankfull Widths

REACH	WIDTH (ft)
Hwy 1	21.5
Peralta	19.9
Adobe	21.5
Capistrano	21.4
Linda Mar	20.0
Oddstad	15.8

It is important to note that even though some sections of channel presently have bankfull widths close to average, many of these sections have already undergone a cycle or two of bank erosion (widening) and have begun to stabilize.

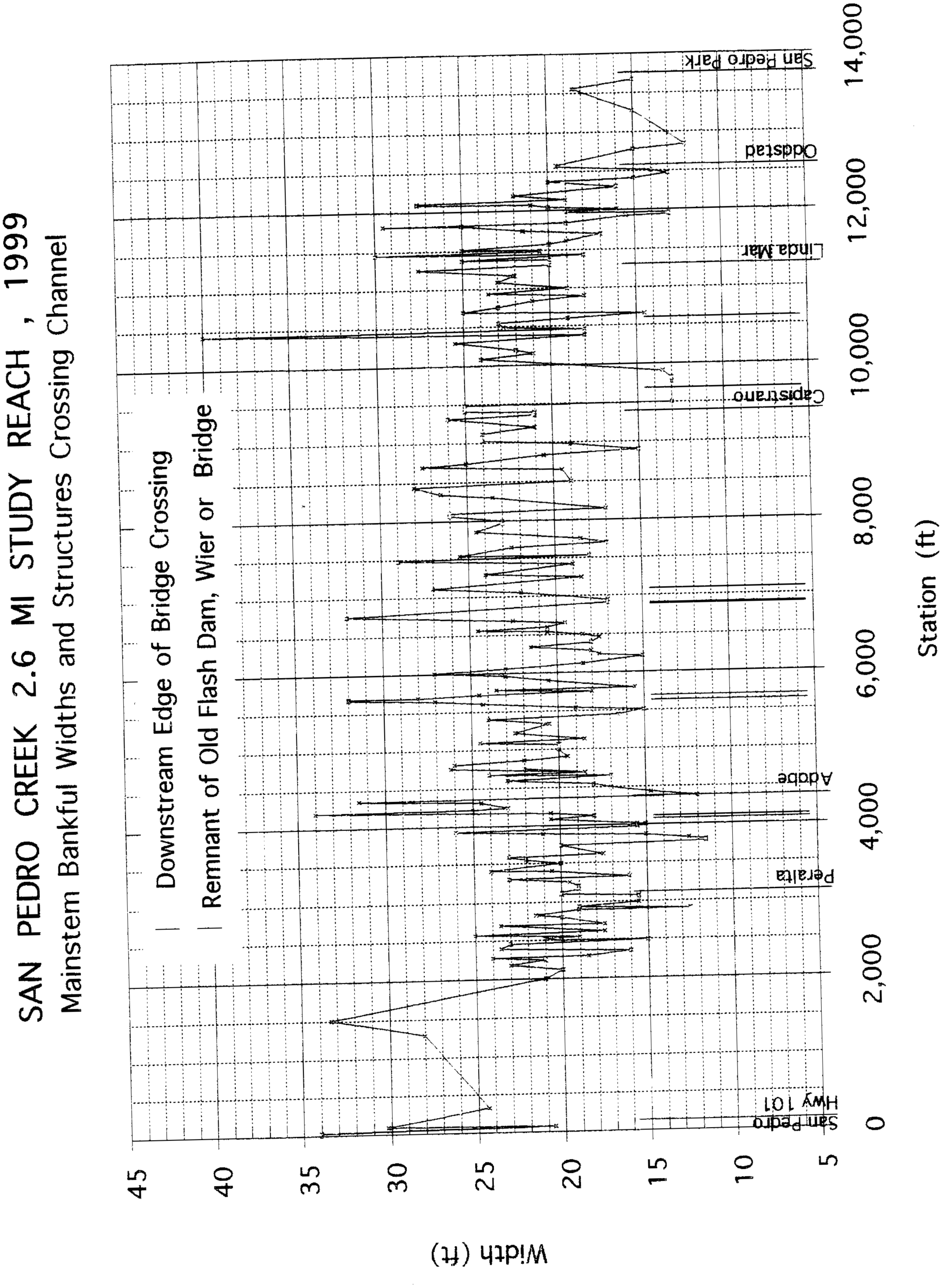


Figure 19. Mainstem Bankfull Width and Structures Crossing Channel

Percent Length Right and Left Bank Conditions

When the amount of bank erosion and stable banks are compared for each side of the stream, as shown in Figure 20, a trend in overall direction of lateral migration can sometimes be detected. In San Pedro Creek, this kind of information is useful for assessing and perhaps planning for long-term trends. The amount of revetment is fairly similar on both sides, about 20%. Yet, the south bank (or left bank for the standard of looking downstream) has 42% of its length eroding compared to 31% on the north side. The historical channel, from what we can determine so far, appears to have occupied the center of the valley before it was ditched and lengthened. It is not clear whether the channel is migrating southward as an influence of the ditching that was done at both ends of the Study Site or if there is just a natural migration southward that is influenced by tectonics or local topographic and/or stratigraphic variations.

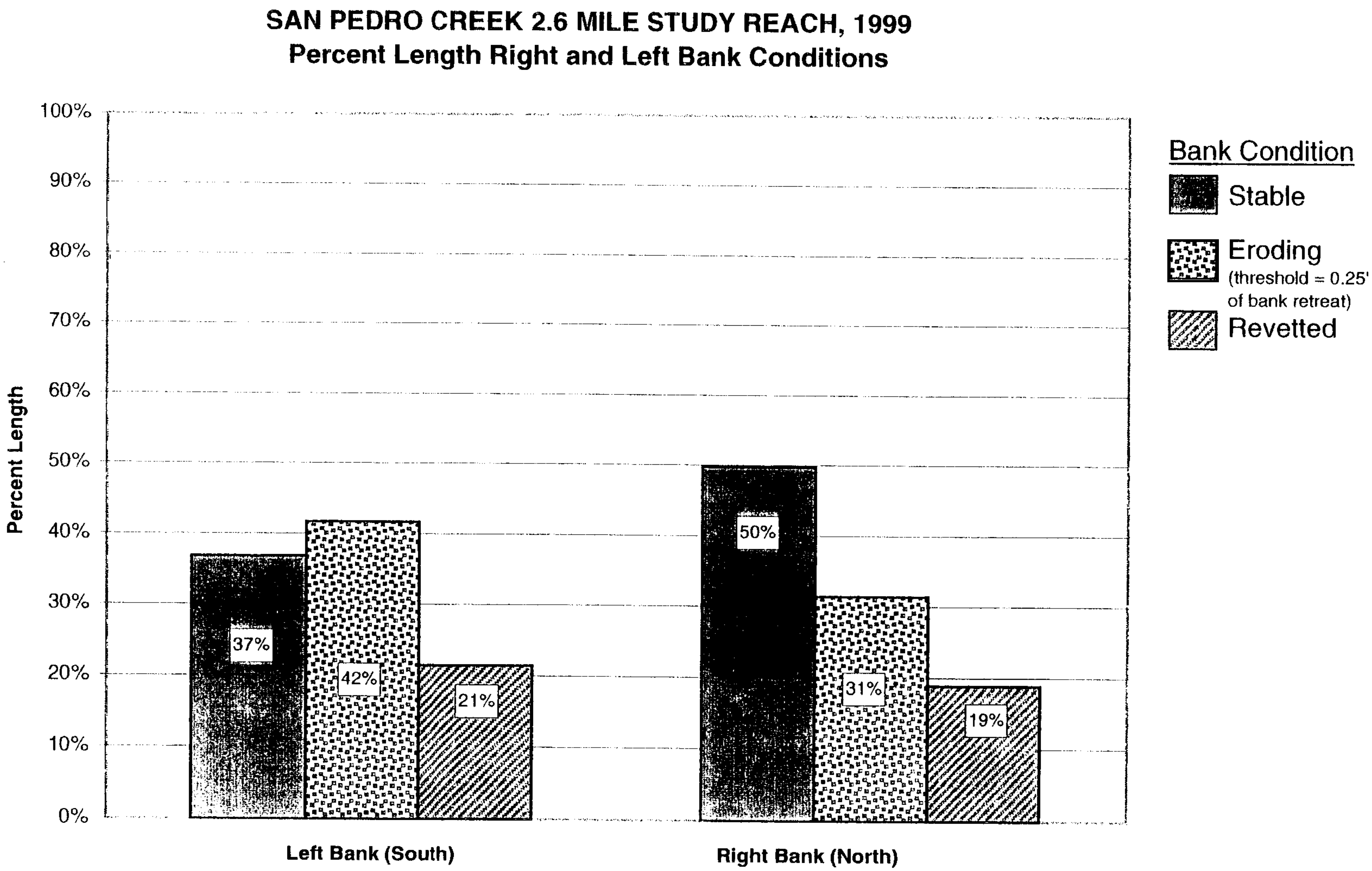
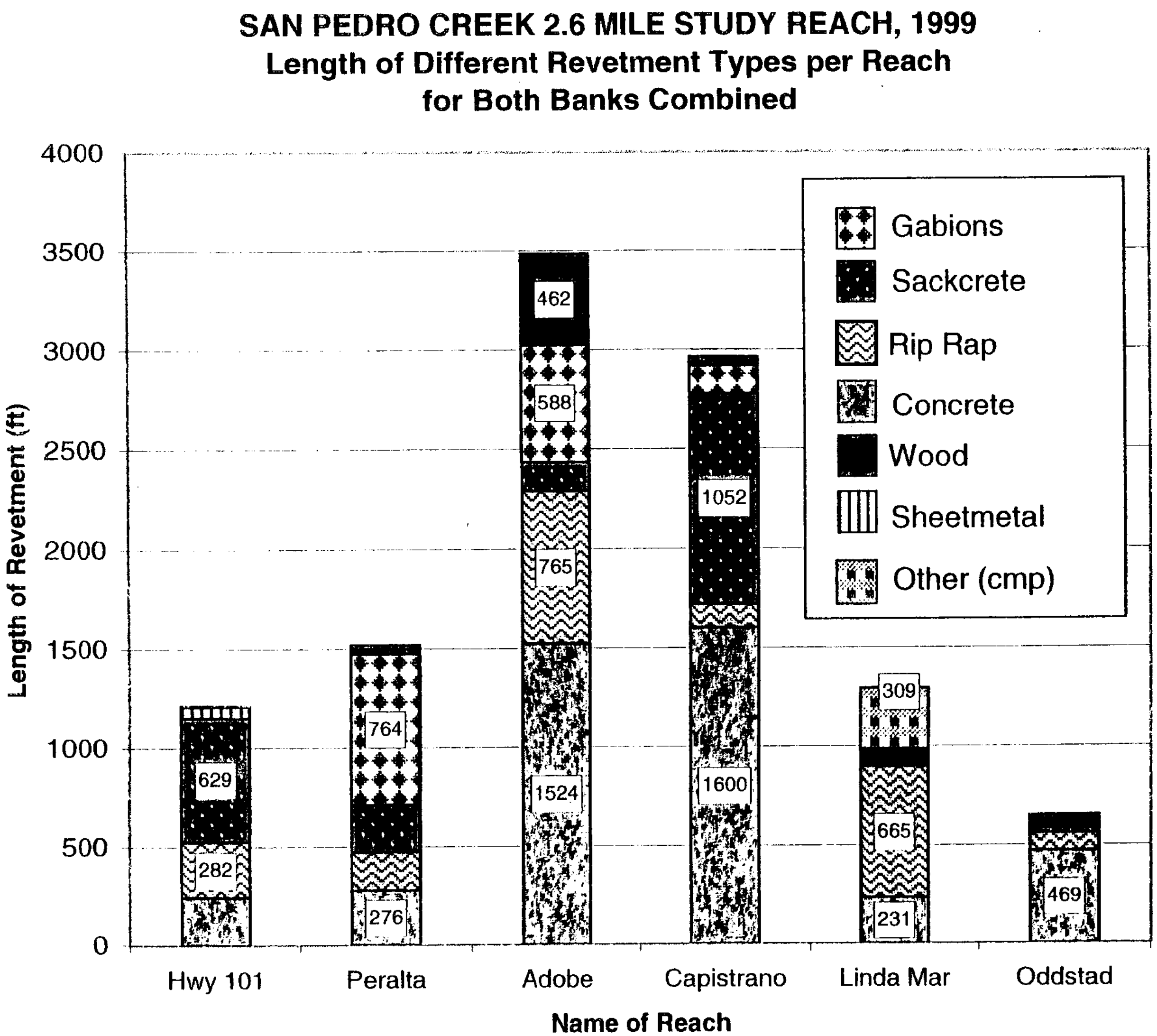


Figure 20. Percent Length of Right and Left Bank Conditions

Length of Different Revetment Types

This graph in Figure 21 shows the kind of revetment that is used on San Pedro Creek banks. The bar graph on the left shows the total length of different revetment types per reach, while the pie chart on the right shows the total percent length and actual length of revetment types for the entire Study Site. Recall from graphs discussed earlier that revetments only represent about 20% on the channel length. As shown in the pie chart 42% of the length is concrete. Sackcrete and riprap each represents another 19%. Wire basket gabions represents another 13% of channel length. Wood, sheet metal and other materials add up to the remaining 10%. These amounts of revetment, which total over half a mile in length, represent considerable cost and effort by land owners and agency managers to minimize loss of property.

The bar graph that stratifies the amount of revetment by reach shows that most of the concrete banks are located in Capistrano and Adobe Reaches. Sackcrete is the second dominant type in Capistrano, while riprap rates second in Adobe Reach. Peralta and Adobe reaches also have considerable length of gabions. We noticed a certain amount of failure in several of the older structures, which usually do not provide for long-term stability.



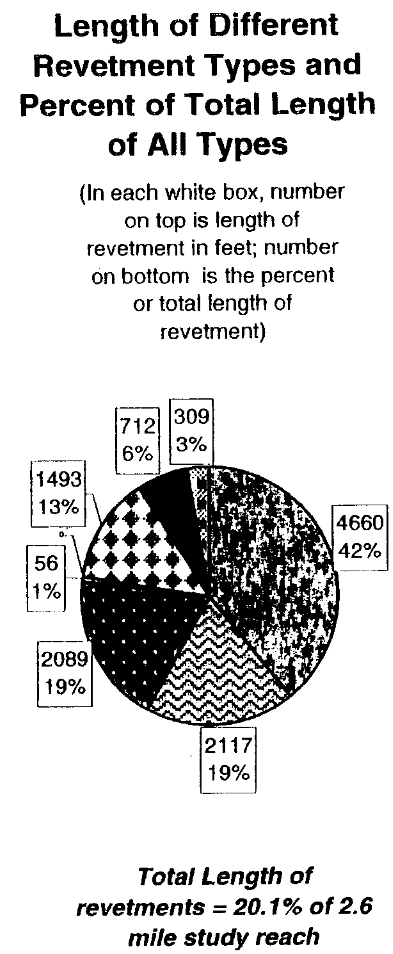


Figure 21. Length of Different Revetment Types

Revetment Conditions per Reach

Condition and performance of individual bank revetments were evaluated at each structure as shown in Figure 22. If at least 85% of a structure was functioning as designed, it was rated as good. If only 50% - 85% was functioning, it was rated as moderate. If less than 50% was functioning, then it was rated as failing. To evaluate the revetments, we had to determine their functions. All were designed to reduce fluvial erosion of the banks. In other circumstances, not present within the Study Site, they may also be designed to reduce mass wasting by holding up a hillside that is landslide prone, for example.

Adobe and Linda Mar Reaches had the greatest length of revetment rated as both failing and moderately functioning. The types of revetments that had the greatest amount of failure were gabions, concrete debris and rock riprap. The riprap category includes both rock and concrete rubble. In the past, the use of such kinds of riprap did not necessarily require engineering assessments. Most of the revetment in the watershed is rated as in good condition. This is because most of it is engineered concrete structures, which may have an advantage for stability but take an ecological toll. For example, riparian vegetation is minimized, the banks are hardened and the channel cannot meander, water velocities are increased which can cause an increase in bed incision or bank erosion downstream and across from the revetment. It was not uncommon for us to see evidence of undermining of concrete aprons along the older concrete walls.

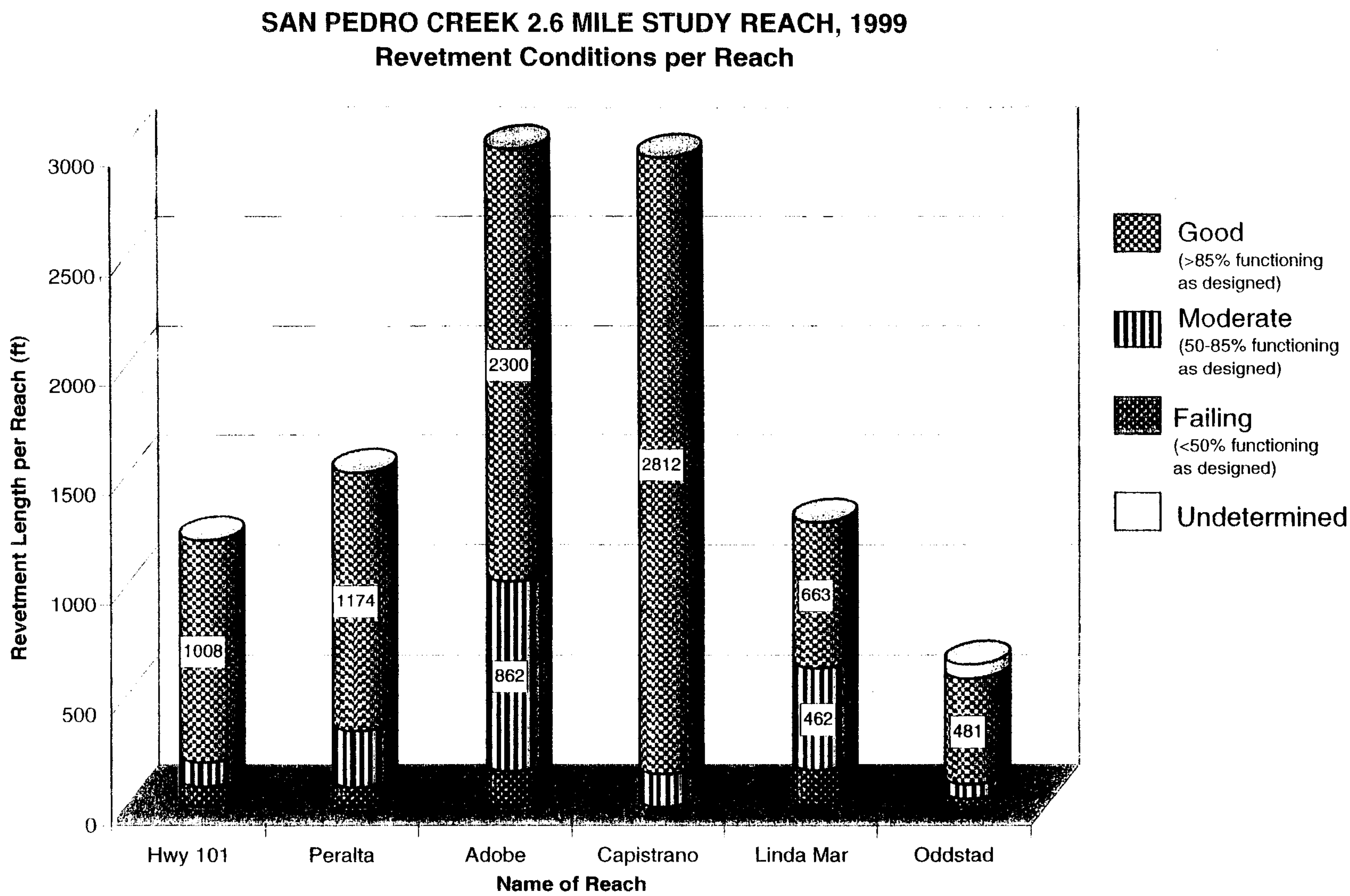


Figure 22. Revetment Conditions per Reach

Percent of Adjacent Bank, Terrace and Landslide Erosion
The length of erosion for banks above and below bankfull elevation can be compared to determine whether erosion is limited to the lower banks or extends up onto the terraces. Highly entrenched channels will show a nearly equal amount of length of terrace erosion as bankfull banks. Figure 23 shows two graphs. The graph on the right summarizes the length of erosion per bank feature for the entire Study Site. The graph on the left stratifies the information by reach as a percent of total reach length.

The pie chart indicates that about 56% of the length of eroding banks are from fluvial erosion of the banks below bankfull elevation. About 43% are from fluvial erosion of terrace banks. Less than 1% is from erosion of banks by landslides. The influence of landslides is minimal through the mainstem of the alluvial valley, but may be much more important along tributary channels.

The graph on the left shows that all reaches have more length of eroding banks below bankfull elevation than above. Adobe Reach has the greatest length of erosion below bankfull elevation, about 29%. It is the only reach influenced by landsliding. Capistrano and Peralta Reaches have nearly equal lengths of eroding banks above and below bankfull. The reaches with more entrenchment have a greater length of terrace erosion than the less entrenched reaches. Highway 1 reach has the least amount of length of eroding terrace bank, only 8%. Oddstad Reach shows the greatest difference in length of eroding terrace and bankfull banks. This might be an indication that this channel is still adjusting its geometry. We observed field evidence that suggests fairly recent incision of the bed.

MECHANISMS AND AMOUNTS OF SEDIMENT SUPPLY

Sediment supplied to a channel throughout a watershed can be associated with varied processes that can be temporally and spatially distributed among multiple sources from varied parts of a watershed. Some examples include bed incision, bank erosion; fluvial transport of bedload; landslides; soil creep; and surface erosion from overland flow on hillsides, roads, cattle trails, and inboard ditches. The amount and rate of sediment supply can be influenced by anthropogenic versus natural causes. If the anthropogenic causes are identified and separated from natural causes, reductions in the rate of supply from the man-related sources could be possible. Restoration or mitigation can be focused on these influences.

Volumes of sediment estimated to be derived from the bed represents the long-term supply from downcutting processes since the time of nonnative land use practices. It does not represent the flux from bedload transport. The amount of sediment supplied by bed incision was determined by multiplying bed width by incision height by length of bed between width measurements. Bed width measurements were taken at the same interval as the bankfull width measurements. We estimated the amount of incision by looking for evidence of old channel beds, nick points in the terrace banks, and dating of trees along the channel.

This project does not create a complete picture of all these influences because it is not a full watershed study. Yet, we can start to identify the amounts and sources of sediment associated with the different processes along just the mainstem channel. In such an

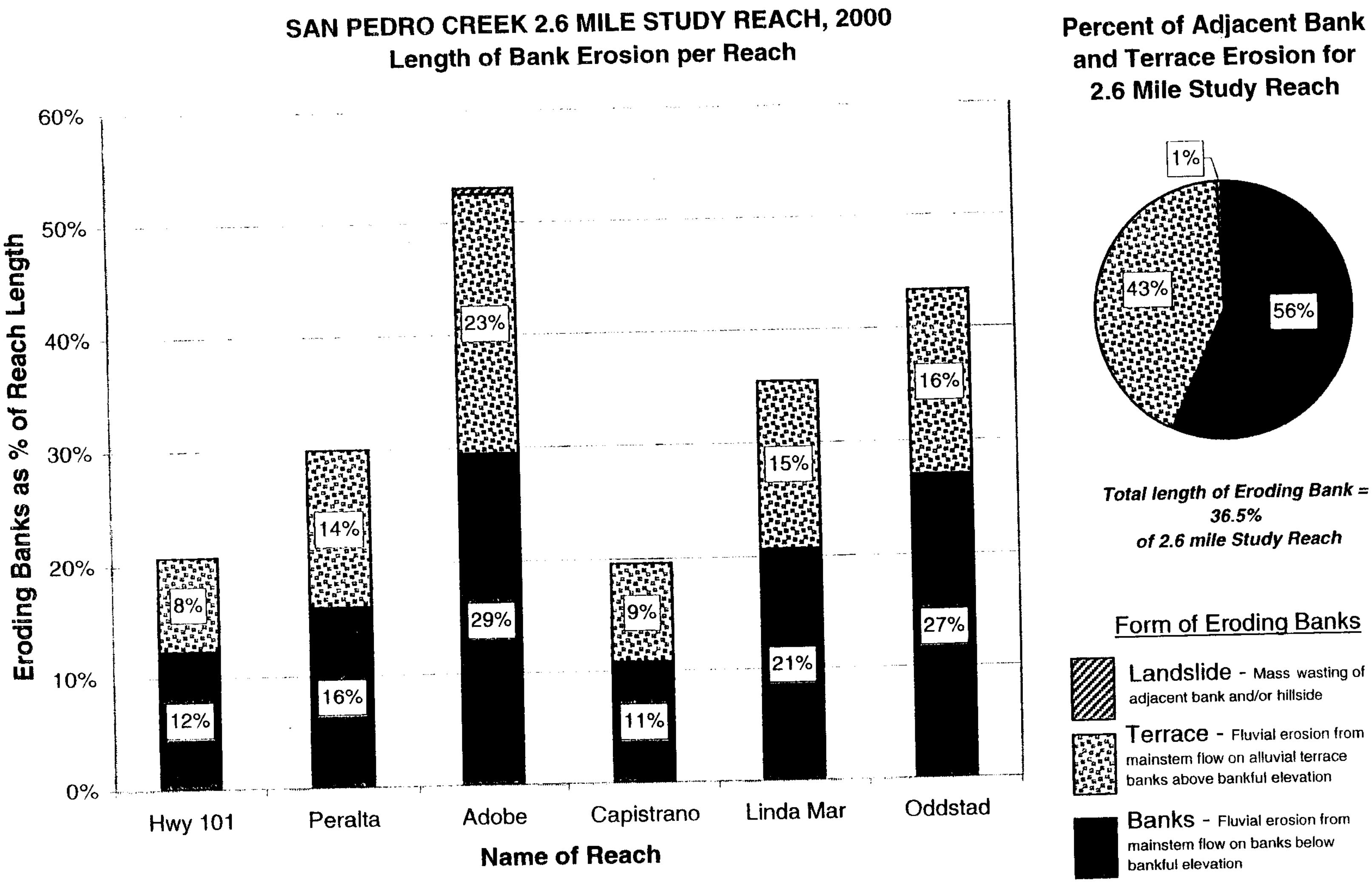


Figure 23. Length and Percent of Bank Erosion Above and Below Bankfull

effort, the volume of sediment contributed from local sources along the length of the Study Site has been identified by its source from bed, banks, gullies, or landslides. Whether these sources can be directly attributed to man-related activities such as culverts, cattle trails, or bridges, for example, is identified only when we have 90% confidence.

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Bank Erosion Volumes per Reach

In San Pedro Creek Study Site the different sediment sources include alluvial terrace banks and banks below bankfull, gullies, and landslides. The graph in Figure 24 on the left shows the volume per linear foot of channel for each reach. The graph on the right shows the total for the entire Study Site. The sediment volume is divided through by the length of each reach. This allows reaches of different length to have their relative volumes compared. This also allows us to compare other creeks that have different study site lengths. The volumes represent the total amount of sediment supplied during the last 217 years.

San Pedro Creek Study Site has had an average of 19 cu ft of sediment per linear foot of creek supplied to it by the banks. This is depicted in the right hand graph. If the total volume of 9870 cu yd is divided through by 217 years, the long-term bank supply rate is about 46 cu yd/year. Actual rates, of course, would be variable where periods of stability would be punctuated by high rates of erosion, such as after the drainage ditch was constructed. Unfortunately, we have not established a definitive date of its construction. Of the total amount of sediment, 74% is supplied by the terrace banks, which is nearly 3 times the amount supplied by the bankfull banks. This is because the channel is entrenched. The respective volumes of sediment supply averaged over the channel length have been 14 cu ft/ft and 4 cu ft/ft. Although the volume of terrace erosion is three times the bankfull amount, the length of eroding terrace banks is 13% less than the bankfull banks. We note that length of bank erosion in channels that have varying degrees of entrenchment is not a good surrogate for the volume of sediment supply. Landslides supply about 1% of the total amount of sediment. Gully erosion on the banks, which is usually associated with surface runoff from culverts, accounts for less than 1% of the sediment supply.

Based upon our field assessment we can confidently attribute at least 25% of the bank erosion to the direct influence of man's activities. About 16% of this volume is associated with erosion caused by instream structures such as revetments, dams, and

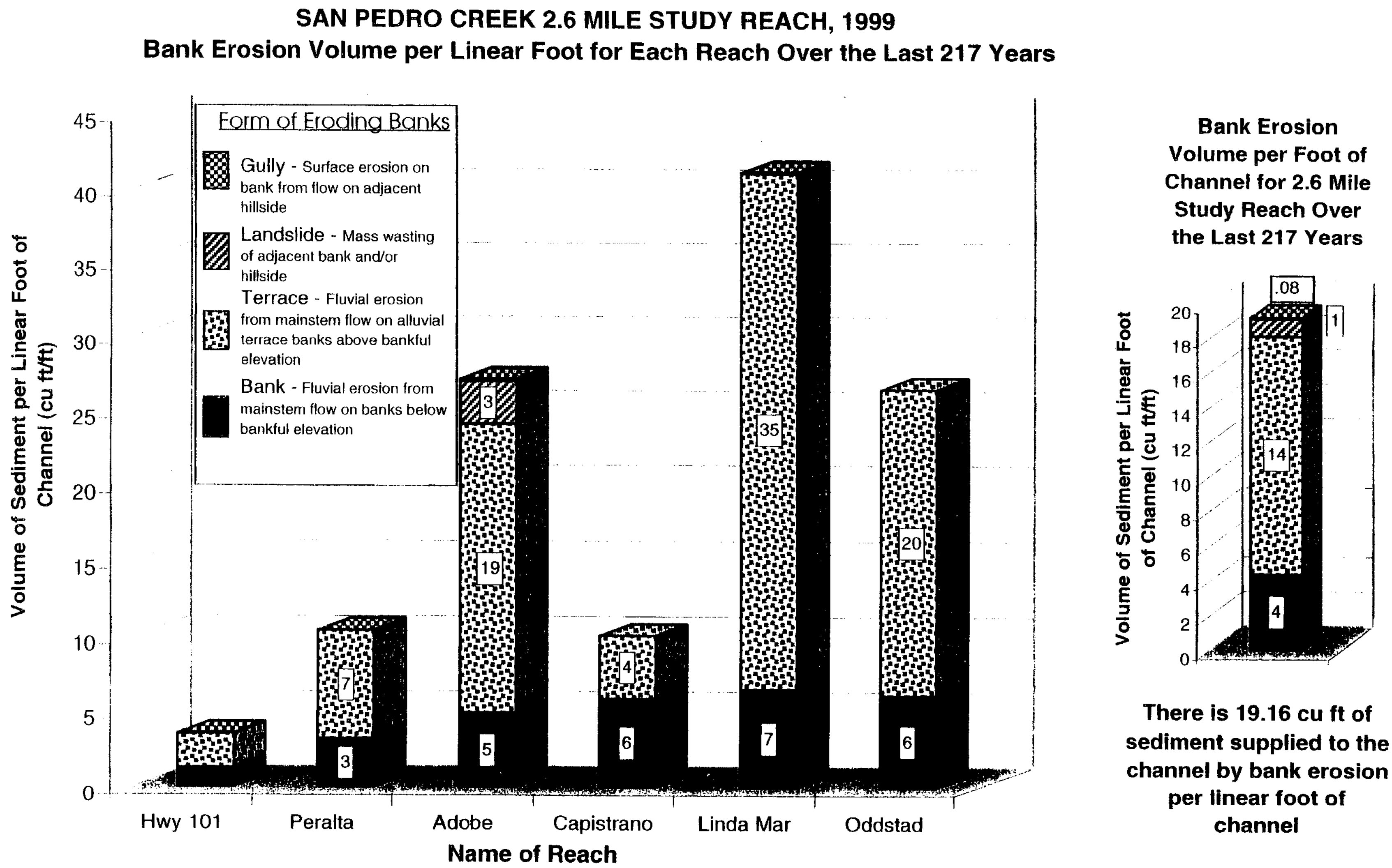

Figure 24. Normalized Sediment Supply from Banks

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Volumes of Bed and Bank Sediment Supply per Linear Foot of Channel during the Last 217 Years

The graph in Figure 25 compares sediment supply per linear foot of channel for the last 217 years. Bank erosion (solid red pattern) is compared to sediment supply from long-term bed incision of channel (stippled red pattern). Note that the bank erosion total includes the supply from gullies on the banks. We also show the combined total of both sources (purple diagonal pattern). The total for the entire Study Site is shown on the far right, while supply for the six reaches are shown to the left. It is important to remember that the total estimated supply from the mainstem does not include upstream tributary sources that are transported as bedload and suspended load to the system.

The graph shows that in all reaches the amount of sediment from bed incision, 145 cu ft/ft, far exceeds the amount from bank erosion. For the entire Study Site, bed supply is over 7 times greater. The reach with the greatest sediment supply from bed incision is Adobe Reach. It is upstream of where San Pedro Creek was put into a drainage ditch, and downstream of the 640 ft concrete-walled channel that has a box culvert/fish ladder structure with 15 ft elevation at Capistrano Bridge. The reach with the greatest combined sediment supply from both bed and bank sources is Linda Mar Reach, which appears to be strongly influenced by increased flows from the culverted North Fork Tributary. The least amount of sediment supply from combined bank erosion and bed incision is the ditch at the Highway 1 Reach. For all the reaches, the range in total sediment supply from combined bed and banks is 53 cu ft/ft to 233 cu ft/ft.

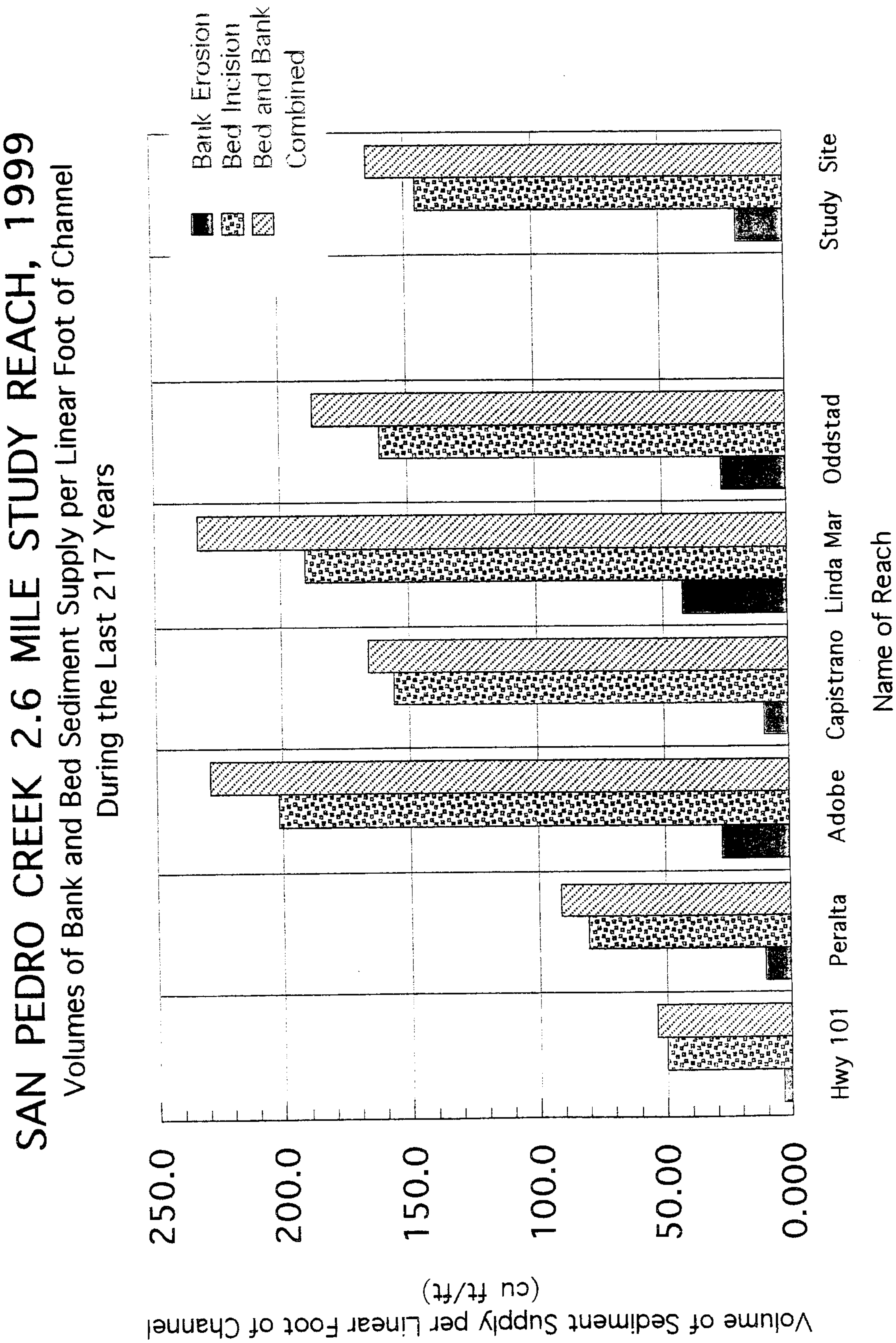

Figure 25. Normalized Bed and Banks Sediment Supply Volumes

The total combined supply for the Study Site is about 165 cu ft per linear foot. If the total amount of supplied sediment is divided by the length of Study Site channel and by 217 years, the total rate of supply is 0.76 cu ft/ft/yr. Thus, in one year the study site would supply 388 cu yd of sediment. The individual sediment supply rates for bed and bank are listed in the table below. A total watershed yield cannot be determined since the rest of the watershed was not quantified.

Table of Sediment Supply Rates for Study Site

SOURCE	Volume in 217 years (cu ft)	Volume per linear foot of channel (cu ft/ft)	Long-term rate per linear foot per year (cu ft/ft/yr)	Long-term rate for Study Site (cu yd/yr)
Banks	266487	19.32	0.09	46
Bed	2006327	145.46	0.67	342
Combined Total	2272814	164.78	0.76	388

The amount of man-related sediment supply that we directly attributed to man's activities is 25%. This supply is from the drainage ditch and from an estimated average of 5 ft incision between Adobe and Capistrano Reach. This is a conservative estimate. We expect that the indirect effects of land use activities would probably cause the percent of man-related bed sediment to be well over 60%. For the combined total amount of sediment, we can confidently say that 25% has been clearly caused by land use practices and indirect effects have probably contributed to well over 60% of the sediment supply.

DISTRIBUTION OF DIFFERENT SIZES OF SEDIMENT ON THE BED SURFACE

Channel gradient, longitudinal curvature, supply of sediment, and downstream sorting causes variations in sediment size over the length of a channel system. Sediment sorting also occurs across the width of a channel from velocity variations caused by flow obstructions. Patches of different-sized sediment can be separated into discrete size classes that can be quantified by performing pebble counts on the particular patches rather than averaging the particle sizes over the entire bed. By performing pebble counts, where particle diameters are measured in the field, the average particle size (D50) is determined by statistical analysis. Once enough pebble counts are performed on different sediment patches, the D50 size class can be reasonably estimated by eye. We have determined that the accuracy is +/- one standard sieve size. The size classes represent the range of standard sieve sizes, which are listed in the legend for Figure 26.

The sediment D50 size classes are used to spatially characterize different reaches of a single channel and to compare the entire channel to other systems. By establishing a continuum of particle size information, it is possible to monitor temporal changes, and determine the influence of tributary channels that may be contributing abundant fine or coarse sediments to the mainstem creek. Additionally, the availability of fine sediments (smaller than 2mm) and their potential for impacts on fish habitat (spawning gravels and pools) can be assessed. Fisheries biologists are also able to assess the availability of appropriate sized spawning gravels for species of interest. The distance stations for the individual bed classes were recorded which provided us the ability to plot their

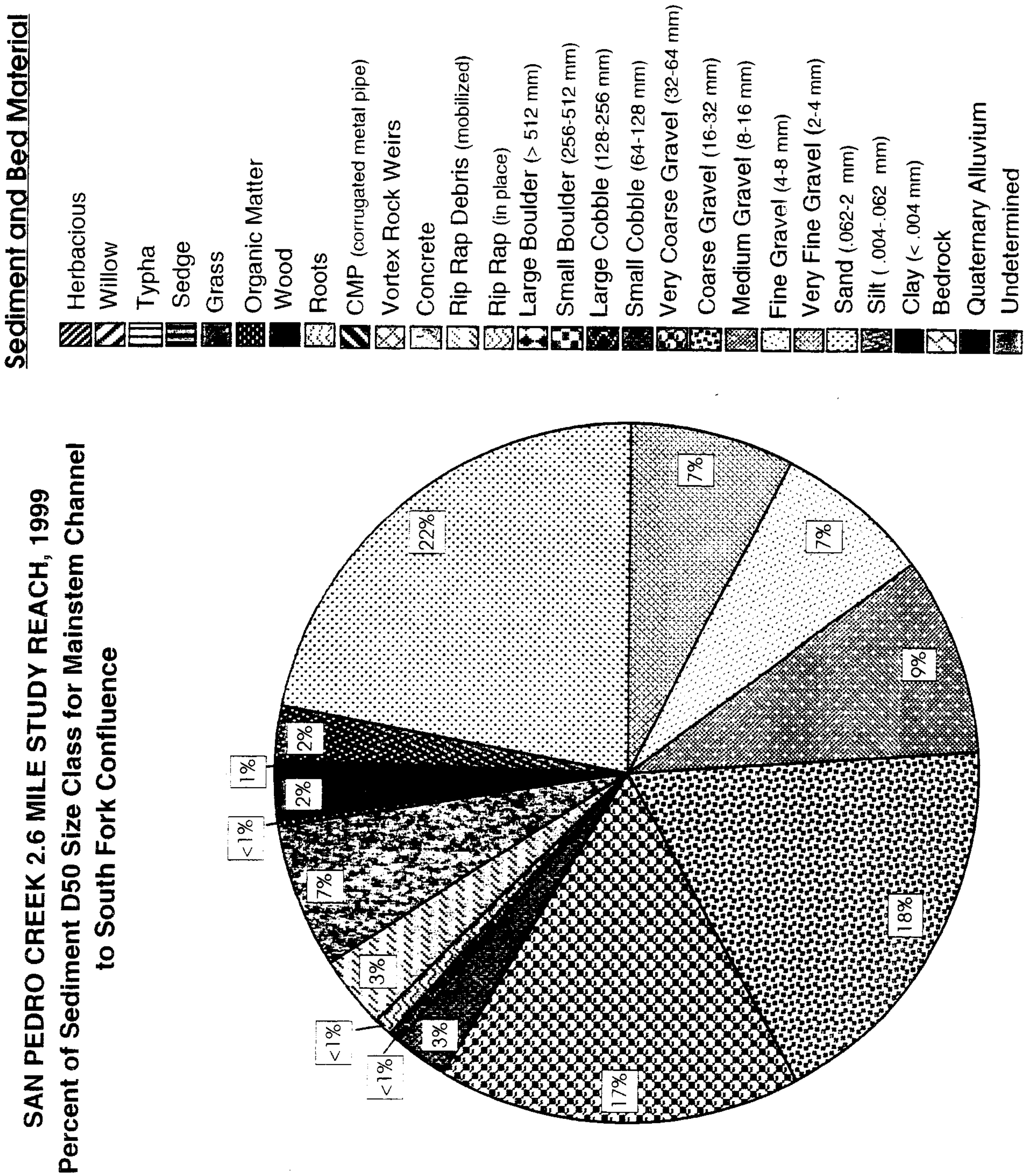

Figure 26. Percent of Bed Surface Sediment D50 Size Class

longitudinal distribution. The specific bed characteristics are shown in the Appendix for Streamline Graphs.

Percent of Sediment D50 Size Classes and Bed Material

Figure 26 shows the D50 size class distribution for the entire length of the Study Site. The dominant D50 size class is sand, representing 22% of the total bed classes. Coarse gravel represents 18% of the bed surface, while very coarse represents 17%. Medium gravel represents about 9%, and fine gravel, very fine gravel, and concrete each represent about 7% of the bed surface. All other size classes individually represent less than 4% of the total, and combined represent less than 13% of the total. About 2% of the bed is represented by Quaternary Alluvium which is a dense clay material, possibly representing an old lake or lagoon environment.

The most distinctive elements about the bed of San Pedro Creek, when it is compared to other Bay Area creeks of similar size and gradient, is the relatively low amount of sand, and very low amount of silt and finer sediments. Nevertheless, we expect that there is more fine sediment in the bed now than 217 years ago. The subdominant coarse and very coarse gravels are considered appropriate–sized gravels for steelhead spawning. Of the 7 Bay Area streams that we have similarly assessed, we are finding a general correlation between streams with viable steelhead habitat to streams with percentages of sand and finer sediments amounting to less than 30% of the total bed surface. Salmonids were observed up to Capoistrano Bridge through the Study Site.

Sediment D50 Size Classes and Bed Material for Different Reaches

Figure 27 shows a general pattern of sediment fining in the downstream direction and coarsening upstream for San Pedro Creek. Although this may seem to be an obvious finding, we have found some other Bay Area streams to have higher percentages of fine sediment upstream, especially in landscapes dominated by earthflow-type landslides in clay-rich bedrock.

The reaches in San Pedro Creek that have the highest percentages of sand and finer-sized sediments, greater than 20%, are Adobe, Highway 1, and Peralta Reaches. Adobe Reach may have slightly higher amounts of fines (sand and smaller–sized sediments) for two possible reasons. A high supply of fines could be directly transported to the reach by Sanchez tributary and/or the bank erosion along Adobe is supplying more fine sediments because the bank composition is finer. Recall that Adobe reach has the greatest length of eroding banks. Fines range from 27% at Adobe to 13% of the surface area at Oddstad. Oddstad has the greatest amount of coarse to very coarse gravels, about 55%, whereas Highway 1 and Adobe Reaches have the lowest amounts, 26%, and 27% respectively. The small cobble D50 size class shows up in all reaches except Highway 1. Mobilized riprap and concrete is present in the bed of all reaches. Adobe Reach has 11% concrete, the greatest amount for any reach. Linda Mar Reach has the greatest amount of riprap placed in the bed, 3% of its length. Quaternary Alluvium (clay beds) is most abundant in Peralta and Adobe Reaches.

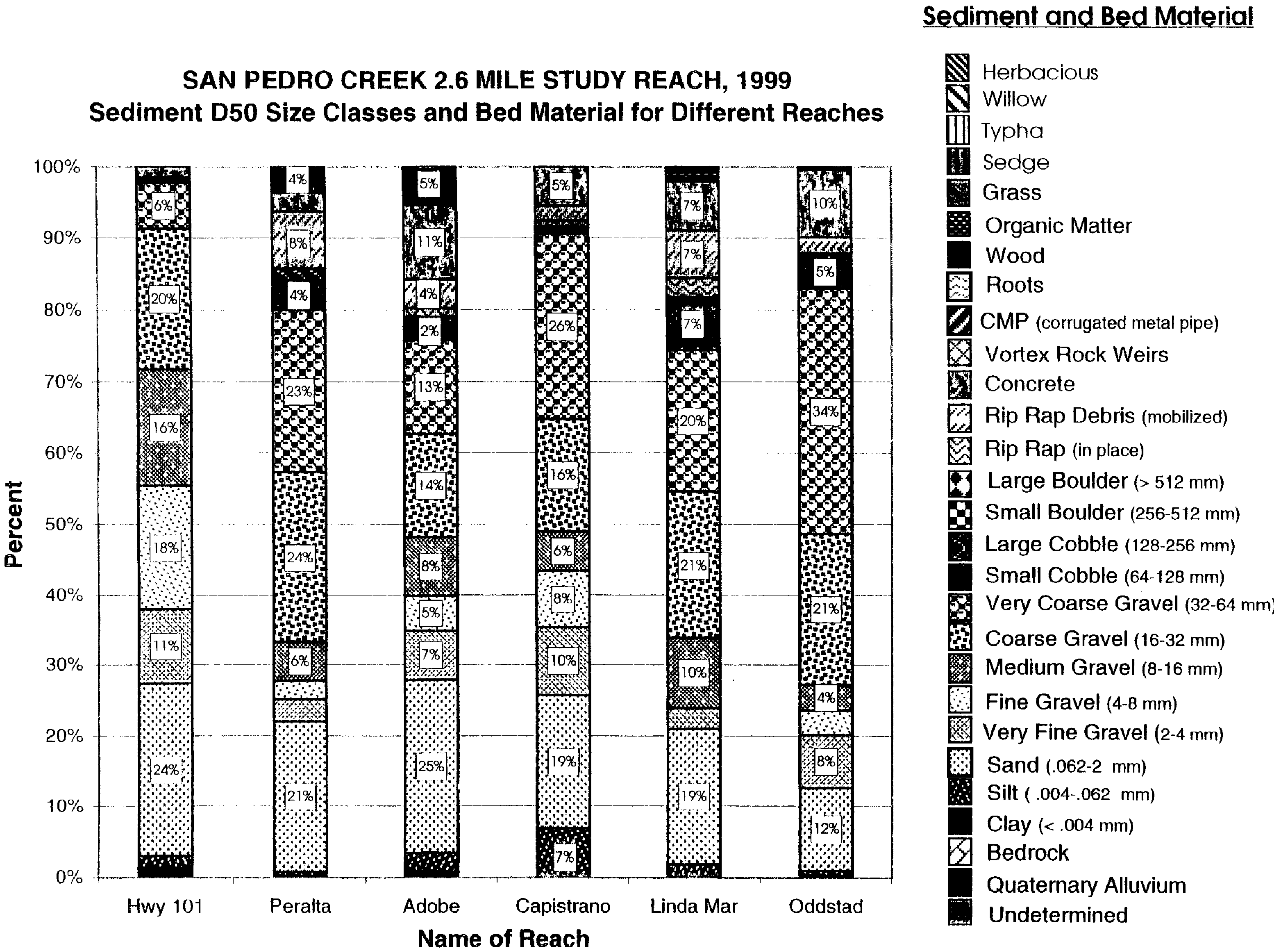

Figure 27. Percent of Bed Surface Sediment D50 Size Class per Reach

SIZE ABUNDANCE AND DISTRIBUTION OF POOLS

In stable channels, systematic downstream variations in velocity will create pools and riffles at predictable intervals. These intervals relate to the wavelength of the meander, where scour and pool formation is typically found at the outside of bends. Because the sinuosity and wavelength of meanders are related to bankfull discharge and gradient of the channel, the minimum expected spacing of pools is usually predictable. For example, in sand or gravel dominated channels of low gradient and well-defined meanders; the expected pool spacing is 5-7 times the bankfull width. In steep, coarser-bedded step-pool channels, pool spacing is often 2-4 bankfull widths. The number of pools in a channel can be much higher than the predicted value when there are flow obstructions of LWD or bedrock, for example. Low pool spacing means that there are a large number of pools per unit length, often a good indication that the channel exceeds the number of pools that would be available if spacing were just based upon curvature alone. It also means more potential habitat for fish. When pool spacing is greater than expected values, meaning a low number of pools per unit length, the channel may be in an unstable form, adjusting to changes in supply or transport of water and sediment.

Only pools greater than 1 ft depth for the low flow condition were documented for this analysis. Maximum pool depth for the low flow condition was measured by subtracting the water depth, at the pool tail-out, from the maximum depth in the pool. Pool volume was determined by multiplying the average width and length for the low flow condition by 1/2 the maximum depth. The location of each pool was documented by recording its distance station. Their specific location, volume, and max depth can be viewed by looking at the Streamline Graphs in the Appendix.

Number and Percent of Different Pool Volume Classes

Figure 28 show that the total number of pools in San Pedro Creek during the summer season was 128. Over the length of the Study Site, pool spacing was one pool per 108 ft of channel length. Since the bankfull width averages about 21 ft, the predicted spacing for 5-7 bankful widths in a natural meandering stream would be 105 ft to 147 ft. Of the total number of pools, 34% were in the volume class of 200-400 cu ft, 27% were 400-800 cu ft, 18% were 100-200 cu ft, and 9% were 50-100 cu ft in volume. Each of the other volume classes individually represented 5% or less. In combination, they represented 12% of the total. The larger pools are expected to provide better cover, cooler water, and potentially more diversity of habitat.

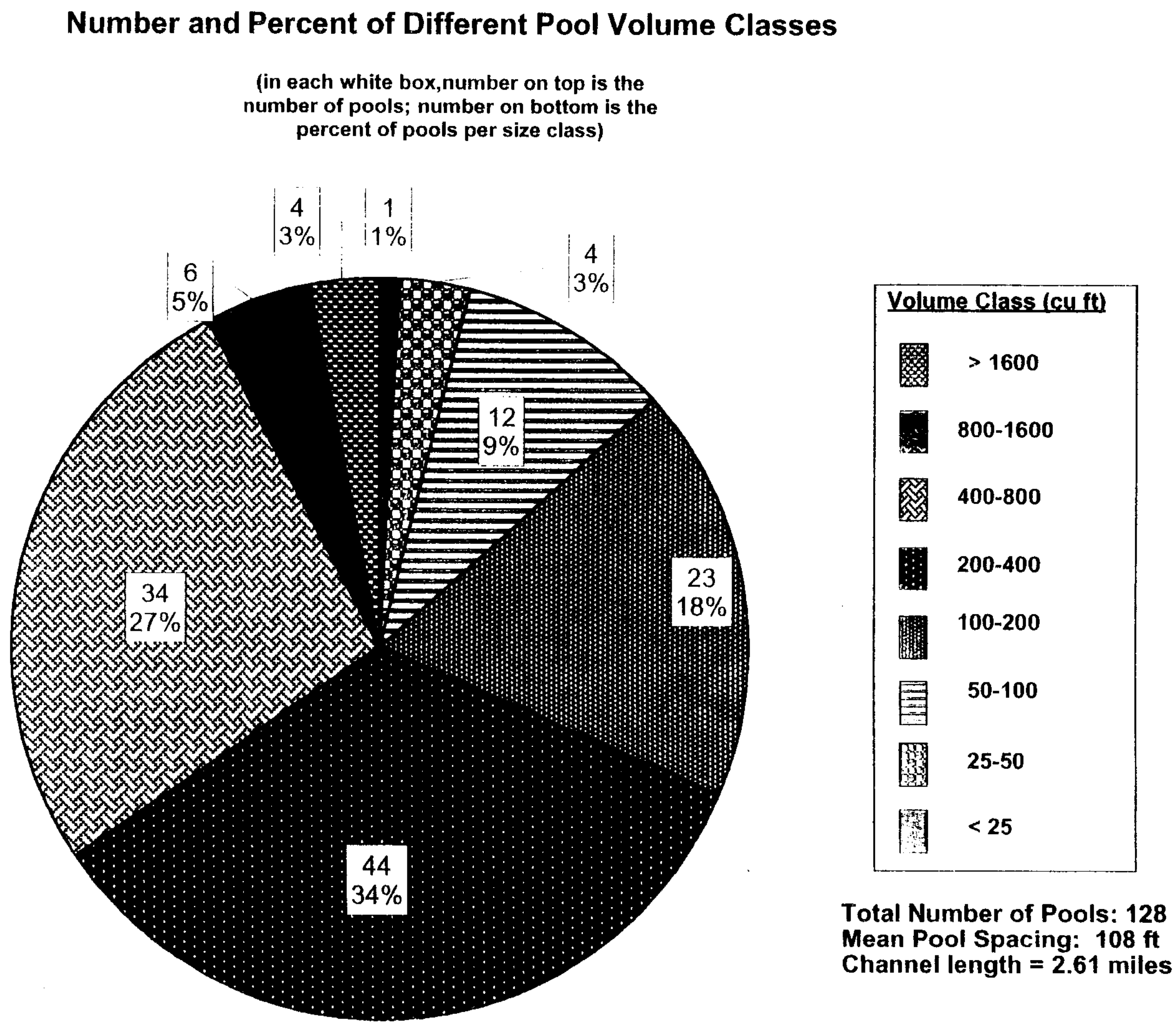

Figure 28. Number and Percent of Different Pool Volume Classes

Number of Pools per Volume Class per Reach

The total number of pools and their associated volume within each reach are shown in Figure 29. During the summer, Adobe Reach had 55 pools, which was the greatest number of pools in any reach, but this reach was also the longest reach. It is best to compare pool spacing, which is the number reported in the yellow box below the reach name. Adobe and Highway 1 Reaches had a similar spacing of one pool about every 90 feet. This means there are more pools than would be predicted if average bankfull width is 21 ft. Peralta and Capistrano Reaches have an expected number of pools, but Linda Mar and Oddstad Reaches have well below the expected number of pools. Their spacing is 182 ft and 406 ft respectively. This may be an effect of reduced discharge above the North Fork confluence that provides perennial flow. All of the reaches have most of their pools volume classes greater than 100 cu ft.

The table below shows the maximum depth classes of the pools. None of the pools are deeper than 5 ft. Most of the pools, 86 of the 128, are less than 2 ft deep. There are 33 pools that have a maximum depth range of 2 ft to 2.9 ft. Adobe Reach has the greatest number of pools for each depth class less than 4 ft. The two deepest pools are in Adobe and Peralta Reach. Most of the prime pool habitat in terms of numbers of pools, volume, and depth are below Capistrano Reach.

Table of Maximum Pool Depths

Reach	Pool Depth Classes				Total
	1-1-9 ft	2-2. 9 ft	3-3.9 ft	4-4.9 ft	
Hwy 1	27	5	1	0	33
Peralta	8	2	1	1	12
Adobe	30	21	3	1	55
Capistrano	14	3	1	0	18
Linda Mar	5	1	1	0	7
Oddstad	2	1	0	0	3
Total	86	33	7	2	128

SAN PEDRO CREEK 2.6 MILE STUDY REACH, 1999
Number of Pools per Volume class per Reach

Total Number of pools = 128

(Pool spacing per linear foot of channel is value shown in yellow box at reach name)

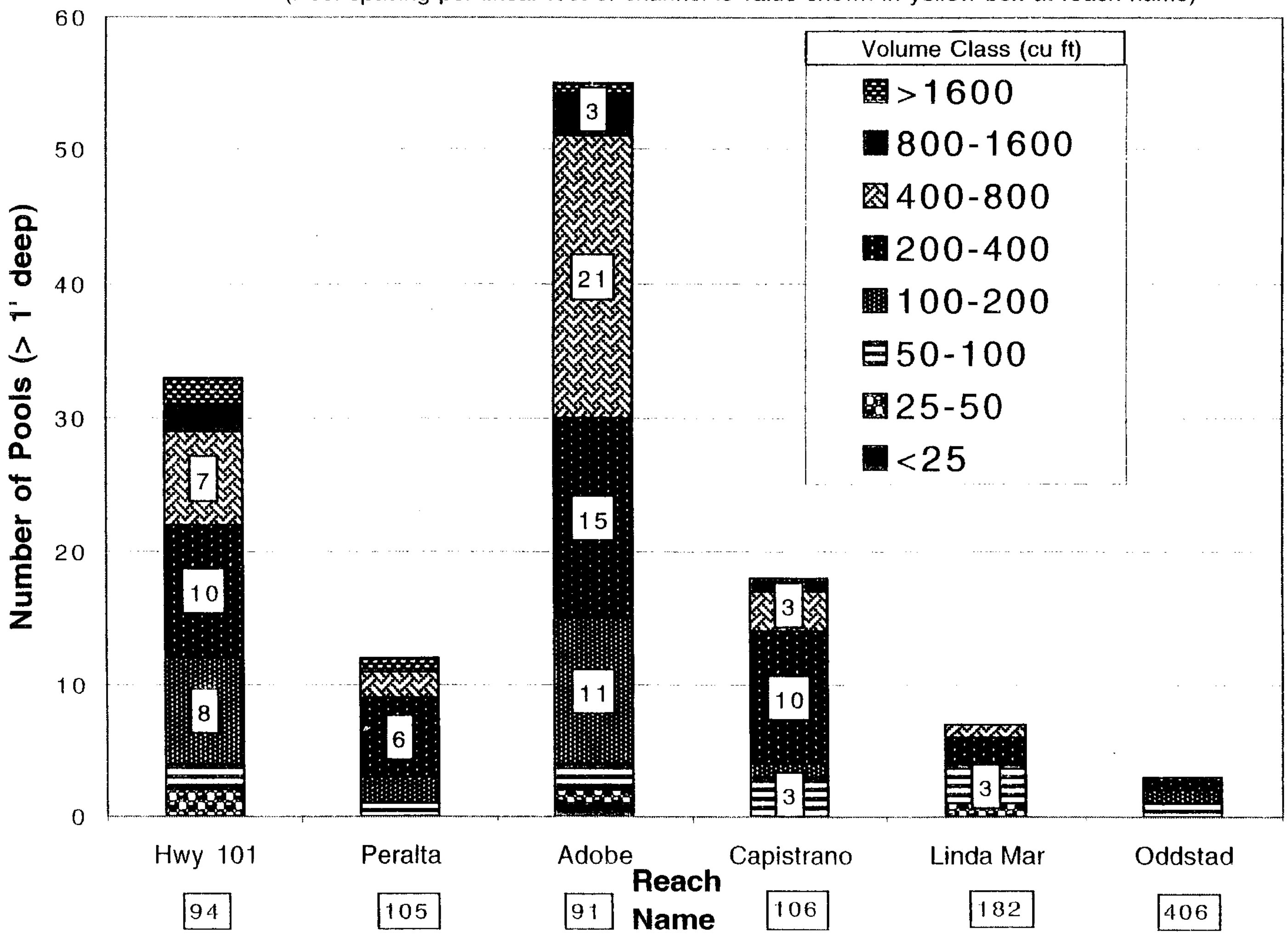

Figure 29. Number of Pools per Volume Class per Reach

CAUSES OF POOLS

During field inspection, the specific or dominant causes producing scour and pool formation were quantified to determine how they influence any particular stream or reach. Specific causes were grouped into five general categories called Natural, Wood-related, man-related, multiple and complex. Natural pools include those pools that form by natural hydraulic processes associated with flow at bends, natural bars, or bedrock abutments, for example. Wood-related pools are caused by scour associated with LWD, tree trunks, roots, or debris jams. The man-related category includes pools caused by man-made structures or by man's activities in the channel. For example, if a pool forms around a large piece of riprap that has been transported from its original placement, the pool is still characterized as man-related. Other man-related pools involve backwaters that form behind structures such as check dams, for example, or pools that form around bridge abutments. If there were several contributing causes, that included a man-related cause with either a natural or wood-related cause, the pool was classified as complex. If the combined causes were natural and wood related the general category would be called multiple. An example would be roots causing scour at an outside bend.

Number of Pools per Volume Class and Their Associated Causes

The remaining summer pools can be stratified by cause of pool and its associated volume, as shown in Figure 30. The number of pools appears to have a normal Gausian distribution for volume classes. However, more pools (49) are caused by man-related causes than either natural or wood-related causes. Many of these pools are associated with failed revetments. Wood-related causes (39) have formed more pools than natural causes (33). Pools that have a volume greater than 800 cu ft are only formed by wood or man-related causes. If pool spacing depended entirely upon natural causes the number of pools would be less than expected for 5-7 bankfull widths. It would equal about 19 bankfull widths. This demonstrates the importance of LWD and mature riparian vegetation for the recruitment of wood to increase the potential number of pools. We expect that the natural category have a low number of pools because the channel does not have its natural curvature since portions of it have been straightened and ditched. Furthermore, several reaches have not achieved a stable geometry for their present supply of water and sediment. While geomorphic adjustments are being made, the number of pools can be less than expected. One mechanism that causes loss of pools in many streams is filling by sand and fine sediments. In San Pedro Creek we did not observe that much pool volume was lost by sand filling during the year that we performed our data collection.

Percent of Adjacent Bank, Terrace and Landslide Erosion
The length of erosion for banks above and below bankfull elevation can be compared to determine whether erosion is limited to the lower banks or extends up onto the terraces. Highly entrenched channels will show a nearly equal amount of length of terrace erosion as bankfull banks. Figure 23 shows two graphs. The graph on the right summarizes the length of erosion per bank feature for the entire Study Site. The graph on the left stratifies the information by reach as a percent of total reach length.

The pie chart indicates that about 56% of the length of eroding banks are from fluvial erosion of the banks below bankfull elevation. About 43% are from fluvial erosion of terrace banks. Less than 1% is from erosion of banks by landslides. The influence of landslides is minimal through the mainstem of the alluvial valley, but may be much more important along tributary channels.

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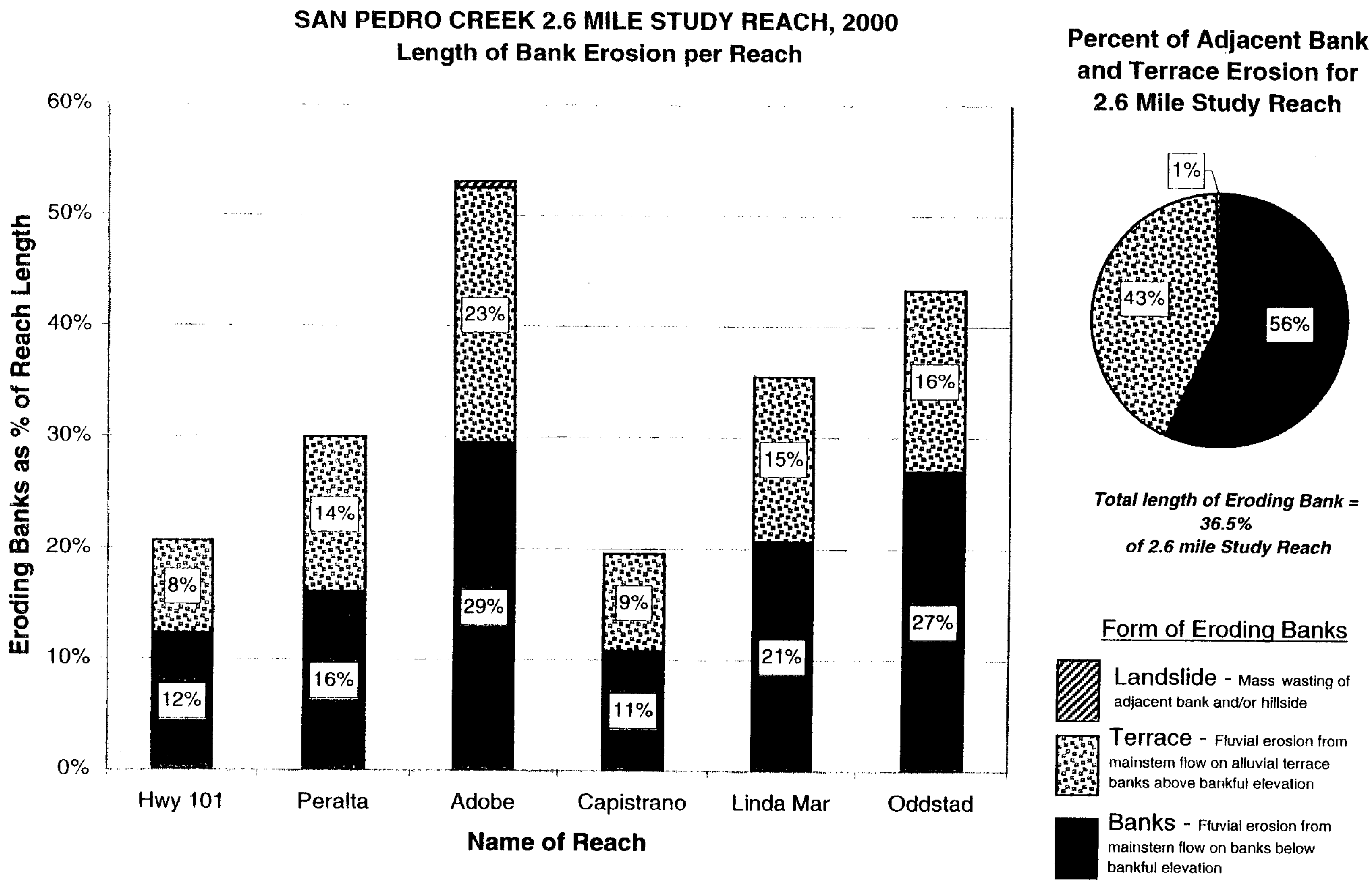

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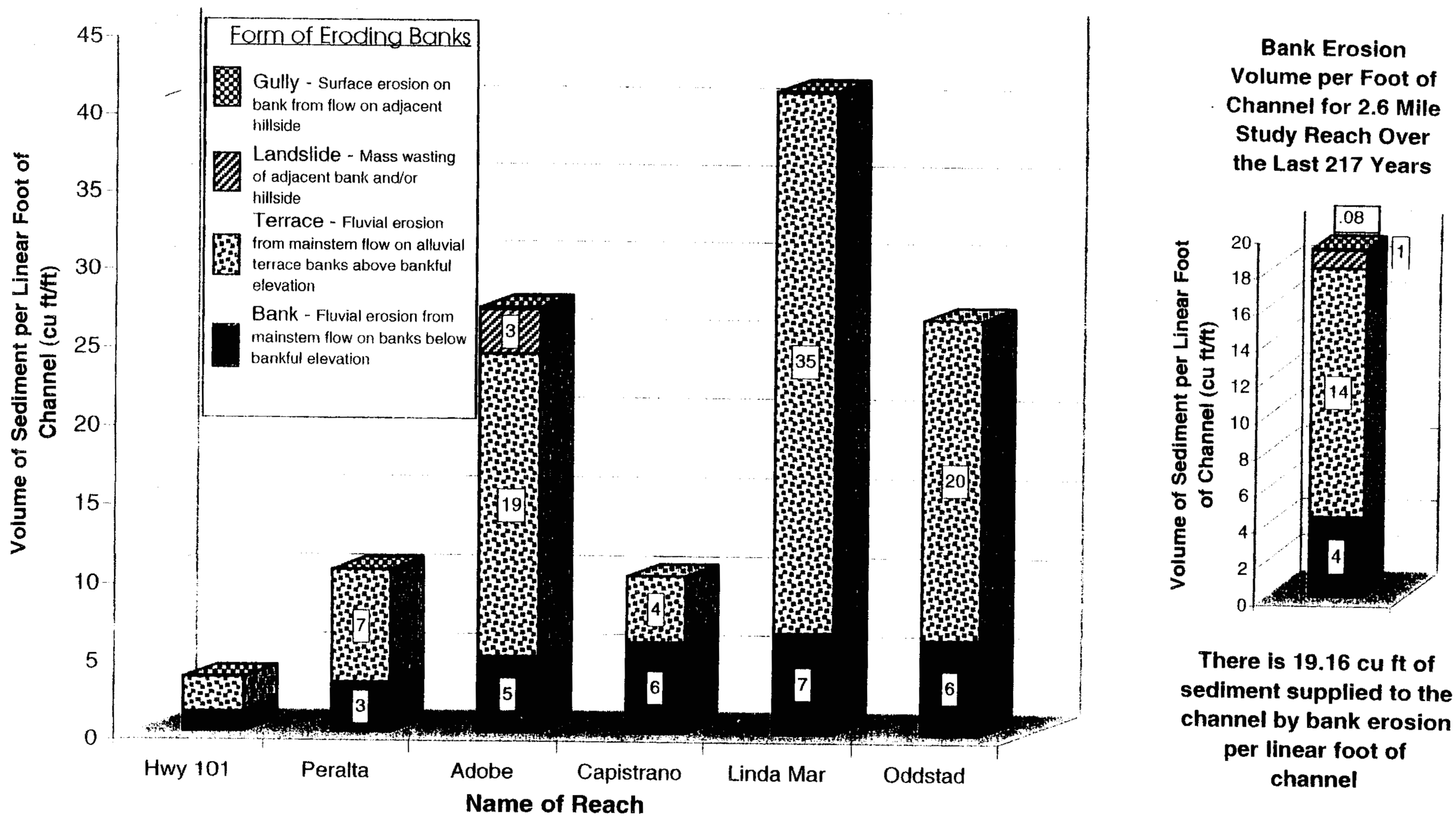
SAN PEDRO CREEK 2.6 MILE STUDY REACH, 1999
Bank Erosion Volume per Linear Foot for Each Reach Over the Last 217 Years



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Adobe and Oddstad Reaches each have nearly comparable sediment supply from the banks, about 26 cu ft/ft. Whereas Peralta and Capistrano Reaches have similar inputs to each other, but are much less than the latter two reaches. They average 9 cu ft/ft. Highway 1 Reach has had the least amount of sediment supply from banks, about 3 cu ft/ft. The amount of sediment supply from gullies is insignificant along the main stem. This process has far greater supply to tributaries on the hillsides. Recall, that the 1853 map showed that gully erosion had already begun on the northwestern hillsides.

Volumes of Bed and Bank Sediment Supply per Linear Foot of Channel during the Last 217 Years

The graph in Figure 25 compares sediment supply per linear foot of channel for the last 217 years. Bank erosion (solid red pattern) is compared to sediment supply from long-term bed incision of channel (stippled red pattern). Note that the bank erosion total includes the supply from gullies on the banks. We also show the combined total of both sources (purple diagonal pattern). The total for the entire Study Site is shown on the far right, while supply for the six reaches are shown to the left. It is important to remember that the total estimated supply from the mainstem does not include upstream tributary sources that are transported as bedload and suspended load to the system.

The graph shows that in all reaches the amount of sediment from bed incision, 145 cu ft/ft, far exceeds the amount from bank erosion. For the entire Study Site, bed supply is over 7 times greater. The reach with the greatest sediment supply from bed incision is Adobe Reach. It is upstream of where San Pedro Creek was put into a drainage ditch, and downstream of the 640 ft concrete-walled channel that has a box culvert/fish ladder structure with 15 ft elevation at Capistrano Bridge. The reach with the greatest combined sediment supply from both bed and bank sources is Linda Mar Reach, which appears to be strongly influenced by increased flows from the culverted North Fork Tributary. The least amount of sediment supply from combined bank erosion and bed incision is the ditch at the Highway 1 Reach. For all the reaches, the range in total sediment supply from combined bed and banks is 53 cu ft/ft to 233 cu ft/ft.

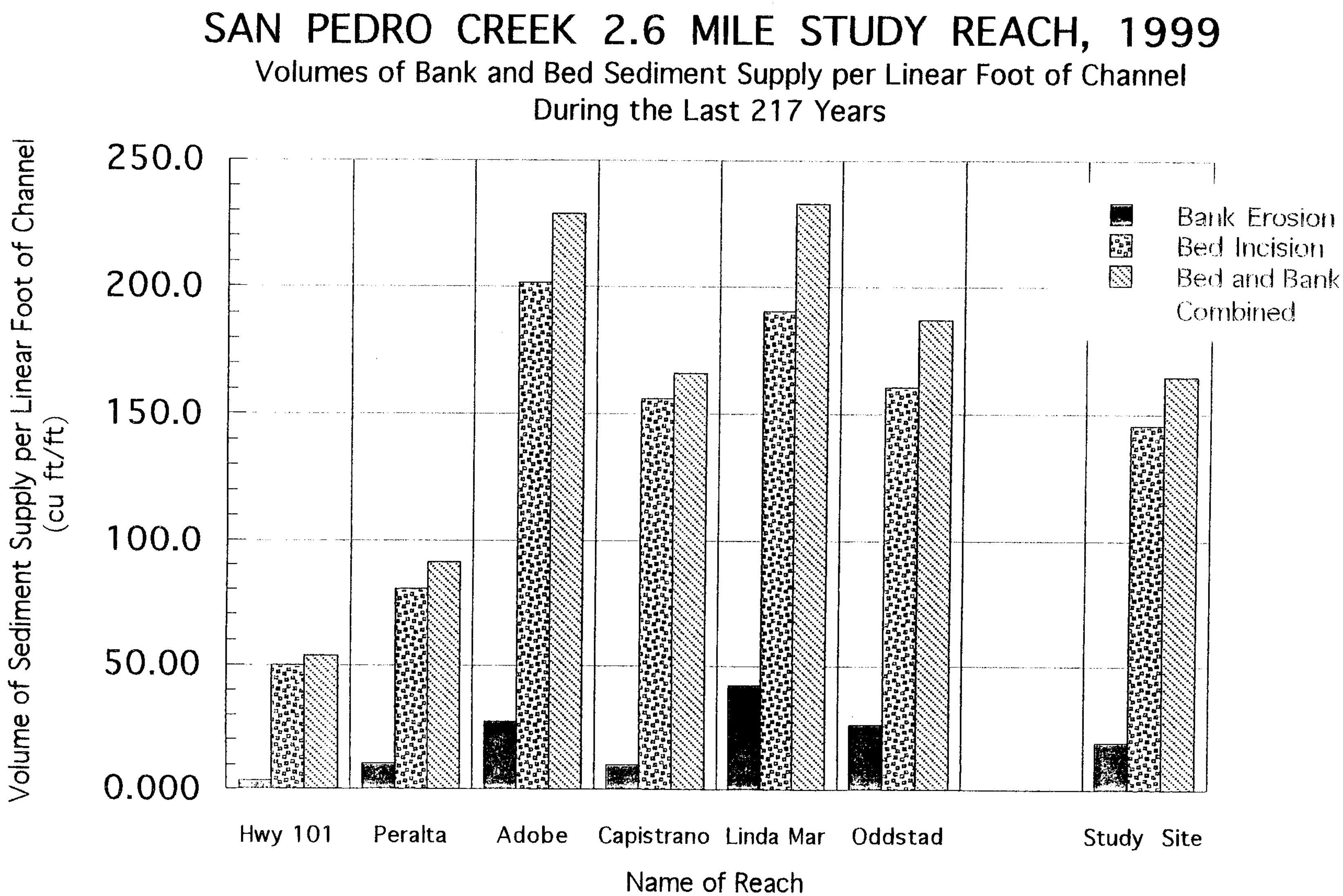


Figure 25. Normalized Bed and Banks Sediment Supply Volumes

The total combined supply for the Study Site is about 165 cu ft per linear foot. If the total amount of supplied sediment is divided by the length of Study Site channel and by 217 years, the total rate of supply is 0.76 cu ft/ft/yr. Thus, in one year the study site would supply 388 cu yd of sediment. The individual sediment supply rates for bed and bank are listed in the table below. A total watershed yield cannot be determined since the rest of the watershed was not quantified.

Table of Sediment Supply Rates for Study Site

SOURCE	Volume in 217 years (cu ft)	Volume per linear foot of channel (cu ft/ft)	Long-term rate per linear foot per year (cu ft/ft/yr)	Long-term rate for Study Site (cu yd/yr)
Banks	266487	19.32	0.09	46
Bed	2006327	145.46	0.67	342
Combined Total	2272814	164.78	0.76	388

The amount of man-related sediment supply that we directly attributed to man's activities is 25%. This supply is from the drainage ditch and from an estimated average of 5 ft incision between Adobe and Capistrano Reach. This is a conservative estimate. We expect that the indirect effects of land use activities would probably cause the percent of man-related bed sediment to be well over 60%. For the combined total amount of sediment, we can confidently say that 25% has been clearly caused by land use practices and indirect effects have probably contributed to well over 60% of the sediment supply.

DISTRIBUTION OF DIFFERENT SIZES OF SEDIMENT ON THE BED SURFACE

Channel gradient, longitudinal curvature, supply of sediment, and downstream sorting causes variations in sediment size over the length of a channel system. Sediment sorting also occurs across the width of a channel from velocity variations caused by flow obstructions. Patches of different-sized sediment can be separated into discrete size classes that can be quantified by performing pebble counts on the particular patches rather than averaging the particle sizes over the entire bed. By performing pebble counts, where particle diameters are measured in the field, the average particle size (D50) is determined by statistical analysis. Once enough pebble counts are performed on different sediment patches, the D50 size class can be reasonably estimated by eye. We have determined that the accuracy is +/- one standard sieve size. The size classes represent the range of standard sieve sizes, which are listed in the legend for Figure 26.

The sediment D50 size classes are used to spatially characterize different reaches of a single channel and to compare the entire channel to other systems. By establishing a continuum of particle size information, it is possible to monitor temporal changes, and determine the influence of tributary channels that may be contributing abundant fine or coarse sediments to the mainstem creek. Additionally, the availability of fine sediments (smaller than 2mm) and their potential for impacts on fish habitat (spawning gravels and pools) can be assessed. Fisheries biologists are also able to assess the availability of appropriate sized spawning gravels for species of interest. The distance stations for the individual bed classes were recorded which provided us the ability to plot their

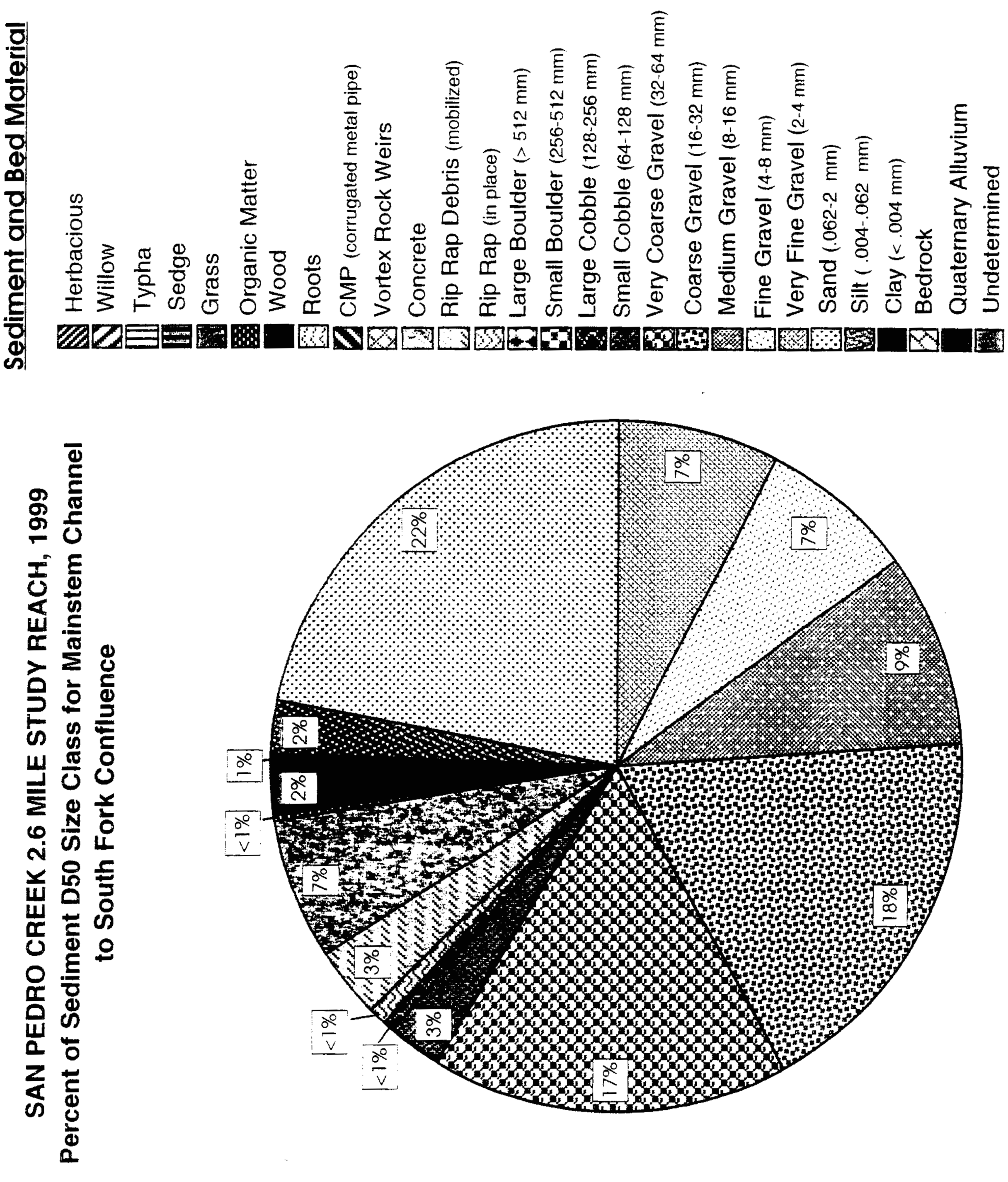


Figure 26. Percent of Bed Surface Sediment D50 Size Class

longitudinal distribution. The specific bed characteristics are shown in the Appendix for Streamline Graphs.

Percent of Sediment D50 Size Classes and Bed Material

Figure 26 shows the D50 size class distribution for the entire length of the Study Site. The dominant D50 size class is sand, representing 22% of the total bed classes. Coarse gravel represents 18% of the bed surface, while very coarse represents 17%. Medium gravel represents about 9%, and fine gravel, very fine gravel, and concrete each represent about 7% of the bed surface. All other size classes individually represent less than 4% of the total, and combined represent less than 13% of the total. About 2% of the bed is represented by Quaternary Alluvium which is a dense clay material, possibly representing an old lake or lagoon environment.

The most distinctive elements about the bed of San Pedro Creek, when it is compared to other Bay Area creeks of similar size and gradient, is the relatively low amount of sand, and very low amount of silt and finer sediments. Nevertheless, we expect that there is more fine sediment in the bed now than 217 years ago. The subdominant coarse and very coarse gravels are considered appropriate–sized gravels for steelhead spawning. Of the 7 Bay Area streams that we have similarly assessed, we are finding a general correlation between streams with viable steelhead habitat to streams with percentages of sand and finer sediments amounting to less than 30% of the total bed surface. Salmonids were observed up to Capoistrano Bridge through the Study Site.

Sediment D50 Size Classes and Bed Material for Different Reaches

Figure 27 shows a general pattern of sediment fining in the downstream direction and coarsening upstream for San Pedro Creek. Although this may seem to be an obvious finding, we have found some other Bay Area streams to have higher percentages of fine sediment upstream, especially in landscapes dominated by earthflow-type landslides in clay-rich bedrock.

The reaches in San Pedro Creek that have the highest percentages of sand and finer-sized sediments, greater than 20%, are Adobe, Highway 1, and Peralta Reaches. Adobe Reach may have slightly higher amounts of fines (sand and smaller–sized sediments) for two possible reasons. A high supply of fines could be directly transported to the reach by Sanchez tributary and/or the bank erosion along Adobe is supplying more fine sediments because the bank composition is finer. Recall that Adobe reach has the greatest length of eroding banks. Fines range from 27% at Adobe to 13% of the surface area at Oddstad. Oddstad has the greatest amount of coarse to very coarse gravels, about 55%, whereas Highway 1 and Adobe Reaches have the lowest amounts, 26%, and 27% respectively. The small cobble D50 size class shows up in all reaches except Highway 1. Mobilized riprap and concrete is present in the bed of all reaches. Adobe Reach has 11% concrete, the greatest amount for any reach. Linda Mar Reach has the greatest amount of riprap placed in the bed, 3% of its length. Quaternary Alluvium (clay beds) is most abundant in Peralta and Adobe Reaches.

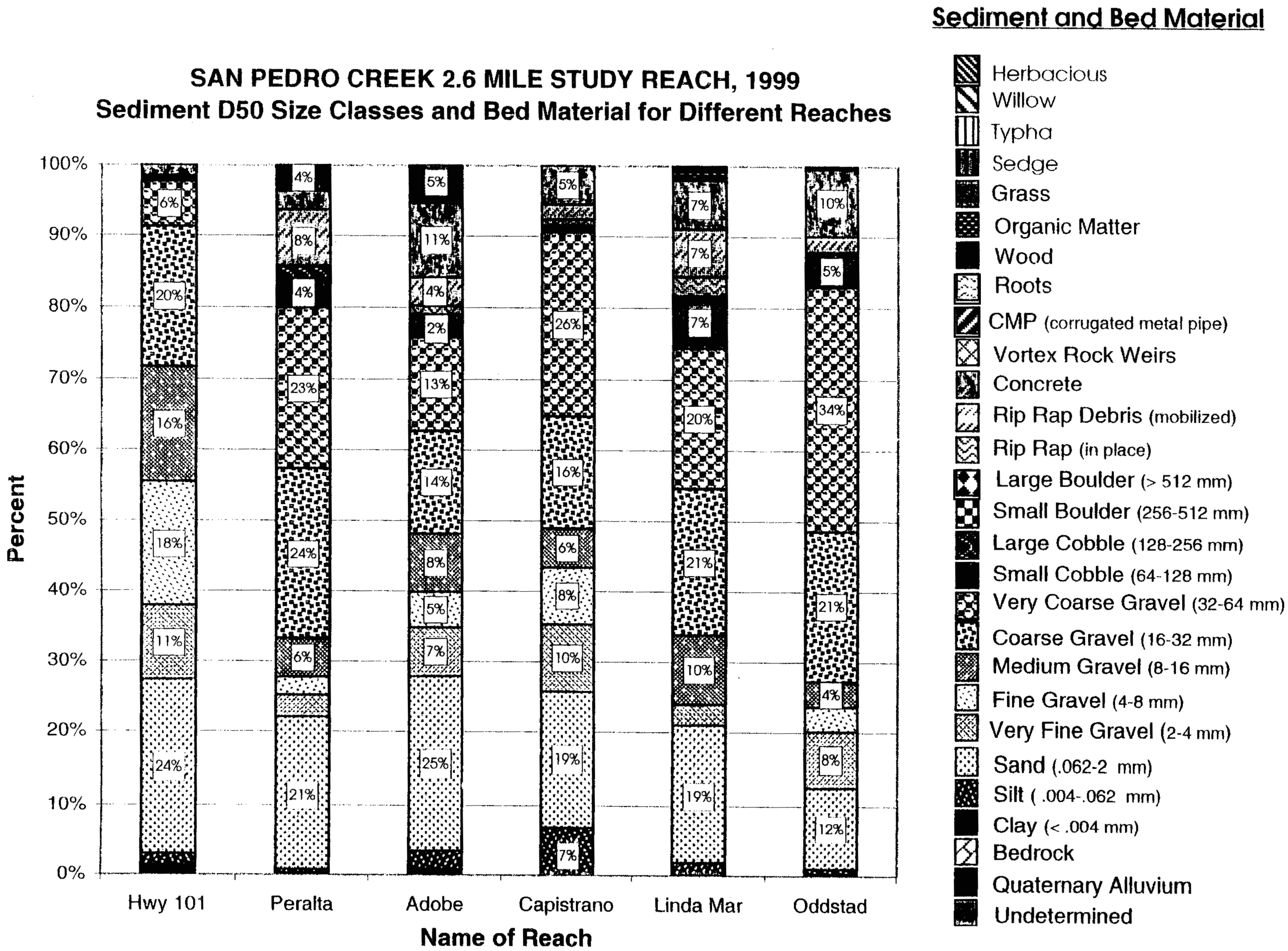


Figure 27. Percent of Bed Surface
Sediment D50 Size Class per Reach

SIZE ABUNDANCE AND DISTRIBUTION OF POOLS

In stable channels, systematic downstream variations in velocity will create pools and riffles at predictable intervals. These intervals relate to the wavelength of the meander, where scour and pool formation is typically found at the outside of bends. Because the sinuosity and wavelength of meanders are related to bankfull discharge and gradient of the channel, the minimum expected spacing of pools is usually predictable. For example, in sand or gravel dominated channels of low gradient and well-defined meanders; the expected pool spacing is 5-7 times the bankfull width. In steep, coarser-bedded step-pool channels, pool spacing is often 2-4 bankfull widths. The number of pools in a channel can be much higher than the predicted value when there are flow obstructions of LWD or bedrock, for example. Low pool spacing means that there are a large number of pools per unit length, often a good indication that the channel exceeds the number of pools that would be available if spacing were just based upon curvature alone. It also means more potential habitat for fish. When pool spacing is greater than expected values, meaning a low number of pools per unit length, the channel may be in an unstable form, adjusting to changes in supply or transport of water and sediment.

Only pools greater than 1 ft depth for the low flow condition were documented for this analysis. Maximum pool depth for the low flow condition was measured by subtracting the water depth, at the pool tail-out, from the maximum depth in the pool. Pool volume was determined by multiplying the average width and length for the low flow condition by 1/2 the maximum depth. The location of each pool was documented by recording its distance station. Their specific location, volume, and max depth can be viewed by looking at the Streamline Graphs in the Appendix.

Number and Percent of Different Pool Volume Classes

Figure 28 show that the total number of pools in San Pedro Creek during the summer season was 128. Over the length of the Study Site, pool spacing was one pool per 108 ft of channel length. Since the bankfull width averages about 21 ft, the predicted spacing for 5-7 bankful widths in a natural meandering stream would be 105 ft to 147 ft. Of the total number of pools, 34% were in the volume class of 200-400 cu ft, 27% were 400-800 cu ft, 18% were 100-200 cu ft, and 9% were 50-100 cu ft in volume. Each of the other volume classes individually represented 5% or less. In combination, they represented 12% of the total. The larger pools are expected to provide better cover, cooler water, and potentially more diversity of habitat.

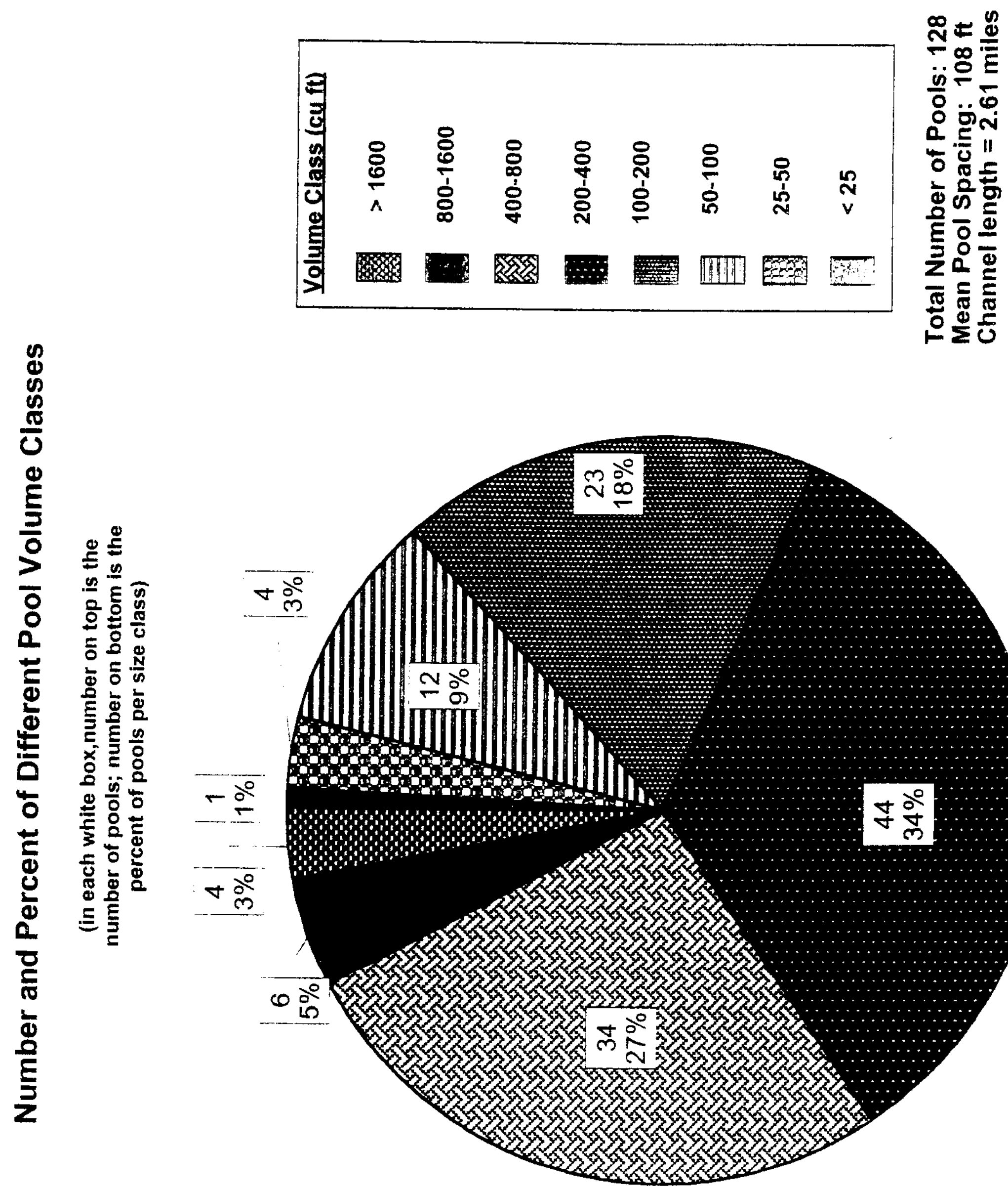


Figure 28. Number and Percent of Different Pool Volume Classes

Number of Pools per Volume Class per Reach

The total number of pools and their associated volume within each reach are shown in Figure 29. During the summer, Adobe Reach had 55 pools, which was the greatest number of pools in any reach, but this reach was also the longest reach. It is best to compare pool spacing, which is the number reported in the yellow box below the reach name. Adobe and Highway 1 Reaches had a similar spacing of one pool about every 90 feet. This means there are more pools than would be predicted if average bankfull width is 21 ft. Peralta and Capistrano Reaches have an expected number of pools, but Linda Mar and Oddstad Reaches have well below the expected number of pools. Their spacing is 182 ft and 406 ft respectively. This may be an effect of reduced discharge above the North Fork confluence that provides perennial flow. All of the reaches have most of their pools volume classes greater than 100 cu ft.

The table below shows the maximum depth classes of the pools. None of the pools are deeper than 5 ft. Most of the pools, 86 of the 128, are less than 2 ft deep. There are 33 pools that have a maximum depth range of 2 ft to 2.9 ft. Adobe Reach has the greatest number of pools for each depth class less than 4 ft. The two deepest pools are in Adobe and Peralta Reach. Most of the prime pool habitat in terms of numbers of pools, volume, and depth are below Capistrano Reach.

Table of Maximum Pool Depths

Reach	Pool Depth Classes				Total
	1-1-9 ft	2-2. 9 ft	3-3.9 ft	4-4.9 ft	
Hwy 1	27	5	1	0	33
Peralta	8	2	1	1	12
Adobe	30	21	3	1	55
Capistrano	14	3	1	0	18
Linda Mar	5	1	1	0	7
Oddstad	2	1	0	0	3
Total	86	33	7	2	128

SAN PEDRO CREEK 2.6 MILE STUDY REACH, 1999
Number of Pools per Volume class per Reach

Total Number of pools = 128

(Pool spacing per linear foot of channel is value shown in yellow box at reach name)

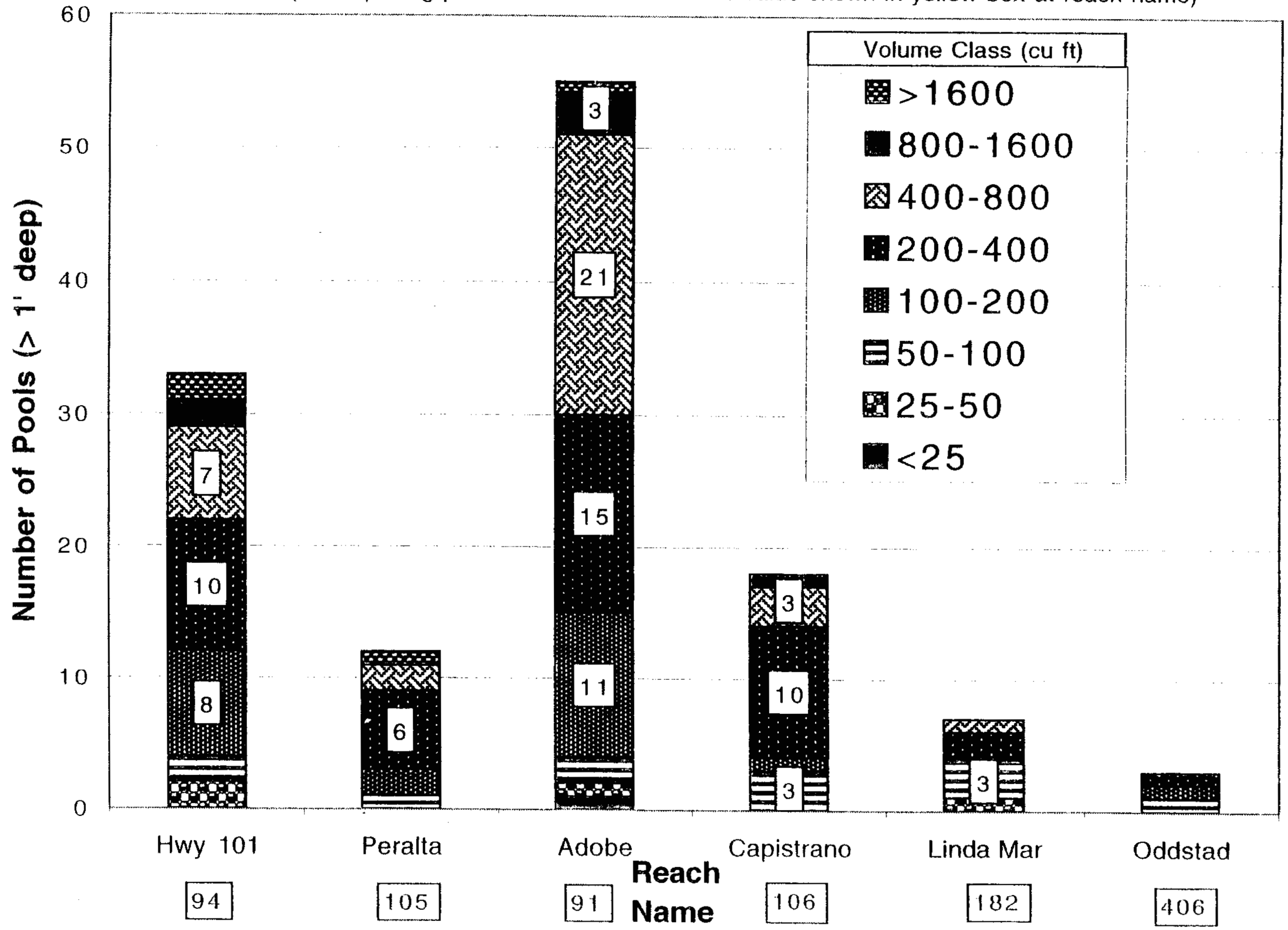


Figure 29. Number of Pools per Volume Class per Reach

CAUSES OF POOLS

During field inspection, the specific or dominant causes producing scour and pool formation were quantified to determine how they influence any particular stream or reach. Specific causes were grouped into five general categories called Natural, Wood-related, man-related, multiple and complex. Natural pools include those pools that form by natural hydraulic processes associated with flow at bends, natural bars, or bedrock abutments, for example. Wood-related pools are caused by scour associated with LWD, tree trunks, roots, or debris jams. The man-related category includes pools caused by man-made structures or by man's activities in the channel. For example, if a pool forms around a large piece of riprap that has been transported from its original placement, the pool is still characterized as man-related. Other man-related pools involve backwaters that form behind structures such as check dams, for example, or pools that form around bridge abutments. If there were several contributing causes, that included a man-related cause with either a natural or wood-related cause, the pool was classified as complex. If the combined causes were natural and wood related the general category would be called multiple. An example would be roots causing scour at an outside bend.

Number of Pools per Volume Class and Their Associated Causes

The remaining summer pools can be stratified by cause of pool and its associated volume, as shown in Figure 30. The number of pools appears to have a normal Gausian distribution for volume classes. However, more pools (49) are caused by man-related causes than either natural or wood-related causes. Many of these pools are associated with failed revetments. Wood-related causes (39) have formed more pools than natural causes (33). Pools that have a volume greater than 800 cu ft are only formed by wood or man-related causes. If pool spacing depended entirely upon natural causes the number of pools would be less than expected for 5-7 bankfull widths. It would equal about 19 bankfull widths. This demonstrates the importance of LWD and mature riparian vegetation for the recruitment of wood to increase the potential number of pools. We expect that the natural category have a low number of pools because the channel does not have its natural curvature since portions of it have been straightened and ditched. Furthermore, several reaches have not achieved a stable geometry for their present supply of water and sediment. While geomorphic adjustments are being made, the number of pools can be less than expected. One mechanism that causes loss of pools in many streams is filling by sand and fine sediments. In San Pedro Creek we did not observe that much pool volume was lost by sand filling during the year that we performed our data collection.

SAN PEDRO CREEK 2.6 MILE STUDY REACH, 1999
Number of Pools per Volume Class and Their Associated Causes

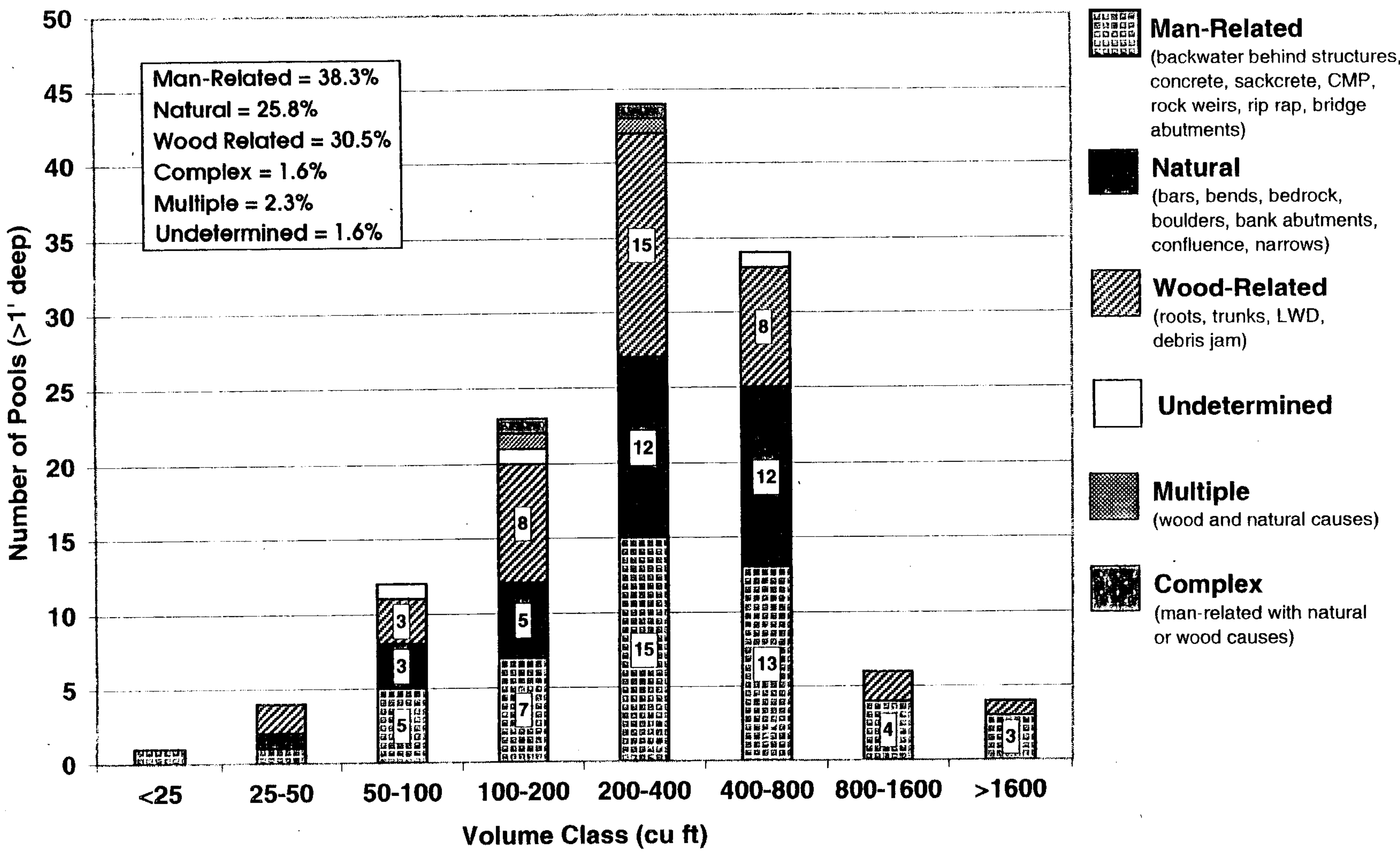


Figure 30. Causes of Pools and Their Volume Classes

DISTRIBUTION AND TYPE OF LARGE WOODY DEBRIS

Large woody debris (LWD) can play a major role in the form and function of streams. It can increase the number to greater than that, which would be expected from bankfull width and channel curvature. It can add diversity, cover and structure to pools or it may trap gravels useful for spawning. Large amounts of LWD can increase the length of time that sediment stays in storage throughout a channel network. Without LWD, sediment transport rates can become accelerated because storage and residence time is decreased. In the past, LWD has been considered a negative asset to streams, particularly urban ones, because it can become trapped at bridges or form natural debris jams that create backwater floods. Therefore, land owners and flood control agencies have commonly practiced LWD removal. Consequently, many streams around the Bay Area and North Coast have become depleted of LWD. Some agencies, such as California Department of Fish and Game, and US Fish and Wildlife Service have developed programs to place wood back into streams.

To assess the amount of LWD in a stream, its average spacing can be assessed, just as for pools. The species of wood that are being supplied and the processes by which it is recruited can also be assessed to determine future trends. This provides a unique mechanistic picture of individual streams and allows us to determine whether the processes or rates of supply of LWD have been altered by land practices.

The location of LWD was recorded relative to its position along the centerline tape pulled in the field. The location of LWD and debris jams is plotted on the Streamline Graphs in the Appendix. To be included in the data set the minimum diameter of the LWD had to be 8 in and it had to be in the active channel bed or intersecting usual bankfull flows. Trees or brush that leaned or hung into the flow that functioned as LWD by producing scour was noted. For example, willows commonly function this way.

Number and Percent of Different LWD Types

The pie chart in Figure 31 shows the number and percent of different species that were counted as LWD in San Pedro Creek. The total number of LWD elements was 198. This represents a spacing of 70 ft. Willows were the dominant species supplying wood. They represented 69% of the total, while alders only represented 12%. Eucalyptus and lumber each represented 9%. Other species of bay, big leaf maple, oak, and pine, each represented 1%.

An obvious change since historical times is the input of non-native species and lumber. We do not expect that the types or necessarily the abundance of native species has changed greatly over time, but perhaps the size of the LWD has. Most of the LWD we observed was not very large in diameter. In fact, the age distribution of trees growing along the ditch and growing within the inner banks was fairly young, since the time of disturbance. The density and maturity of old growth riparian vegetation may have been greater before the onset of channel adjustments that caused the banks to erode and the trees to fall into the channel over the last 217 years. As much of this wood has been supplied to the channel, it has been inadvertently removed to maximize the velocity of flood waters and to minimize potential backwater floods at downstream bridges and box culverts. We have observed numerous trees that after they fell into the channel they were modified by chain saws.

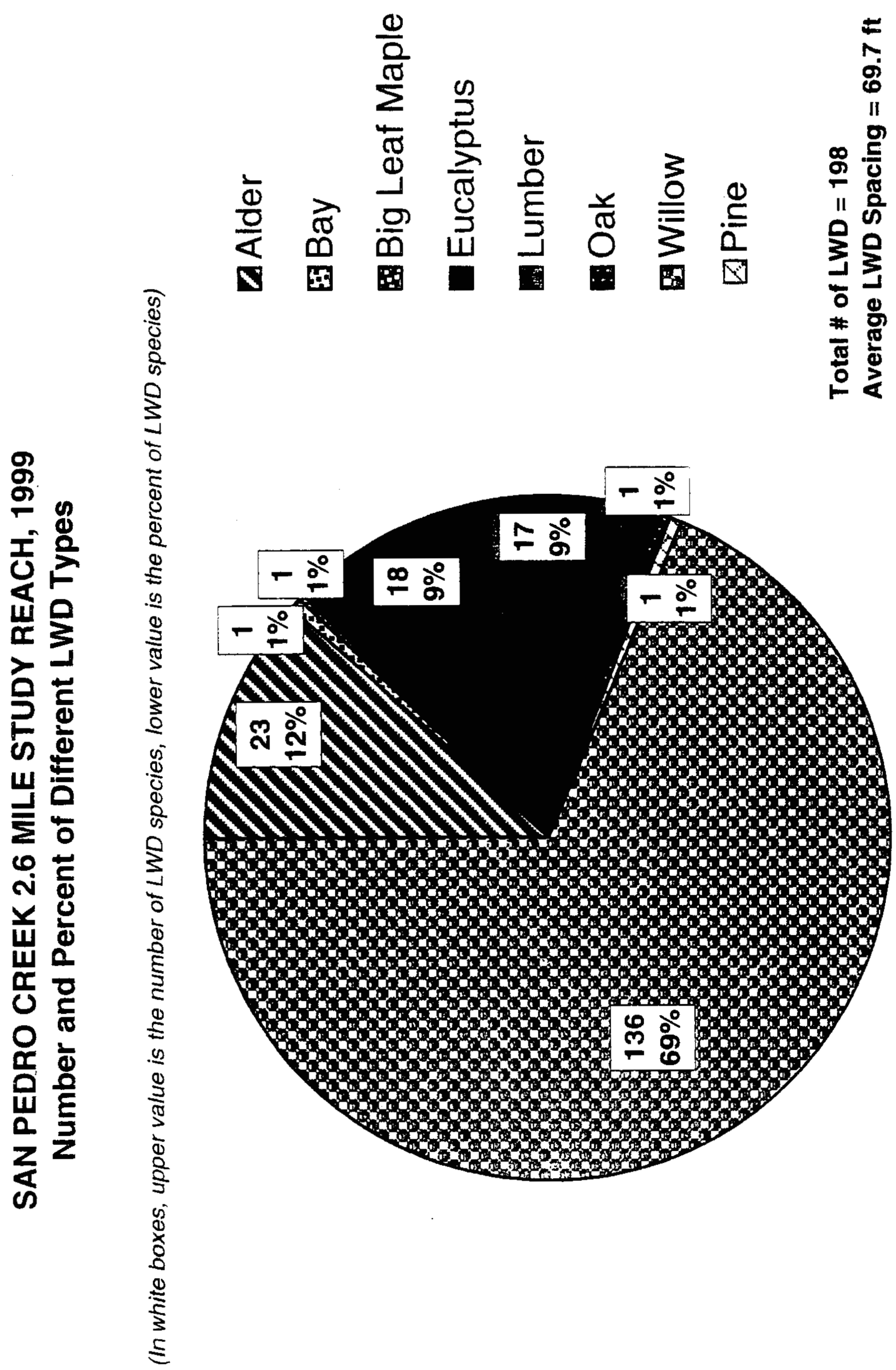


Figure 31. Number and Percent of Different LWD Classes

The way that LWD is lost from a channel system is also of interest. In channels that are not highly entrenched, deposition of LWD onto the floodplain or terraces during floods can remove wood from the active channel bed. As a channel becomes entrenched, there is a greater chance that the LWD will be stored in the system. Its removal becomes dominated by mechanical breakdown or by floating out of the system. The species of trees that comprise the bulk of LWD in San Pedro break down and rot fairly quickly. Thus, LWD residence time would be short-lived as compared to that of oak or bay trees. Relative permanence of pools caused by LWD can be dependent upon the characteristics of the wood. The fact that man is mechanically removing much of the LWD that is of large size limits the potential for many additional pools to form in San Pedro Creek that stay relatively stationary for a period of years. Additionally, since most of the wood is relatively small, it is not aiding much in the storage of sediment or moderating its transport.

Number of LWD Types per Reach

If we look at the distribution of different species comprising LWD over the reaches, Figure 32, it can be seen that Adobe and Highway 1 have the largest quantity of LWD, about 63 pieces in each reach. Linda Mar, Oddstad, and Capistrano also have similar numbers to each other but only about 21 LWD elements. Peralta Reach has the lowest quantity, only 4. Willows and alders are fairly evenly distributed. The distribution of eucalyptus tends to correlate with the location of plantations.

The spacing of LWD is listed for each reach in the white boxes. Although Adobe Reach had the greatest number of LWD, it does not have the lowest spacing. Highway 1, Linda Mar, and Oddstad Reaches have fairly similar spacing, about 1 LWD element per 53 ft of channel length.

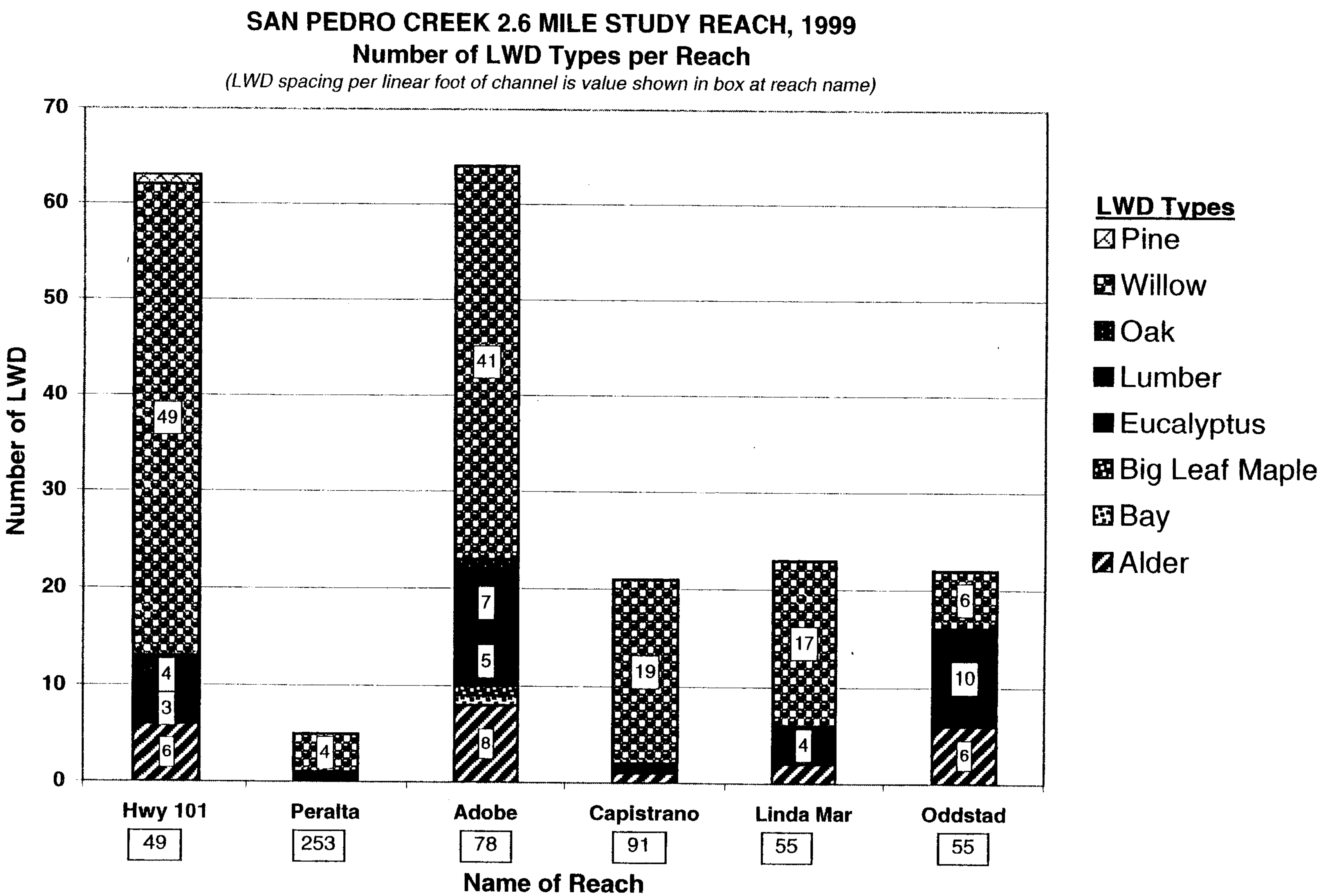


Figure 32. Number of LWD Types per Reach

Debris Jam Characteristics

Figure 33 shows the number and condition of debris jams. There were only two of these features in San Pedro Creek. Deep scour pools are often formed at the downstream end of debris jams, but only one small pool was associated with a debris jam at San Pedro. We suggest the lack of these features indicates removal; otherwise, in an unmanaged system we would expect to see quite a few more debris jams. The debris were not causing much additional sediment storage.

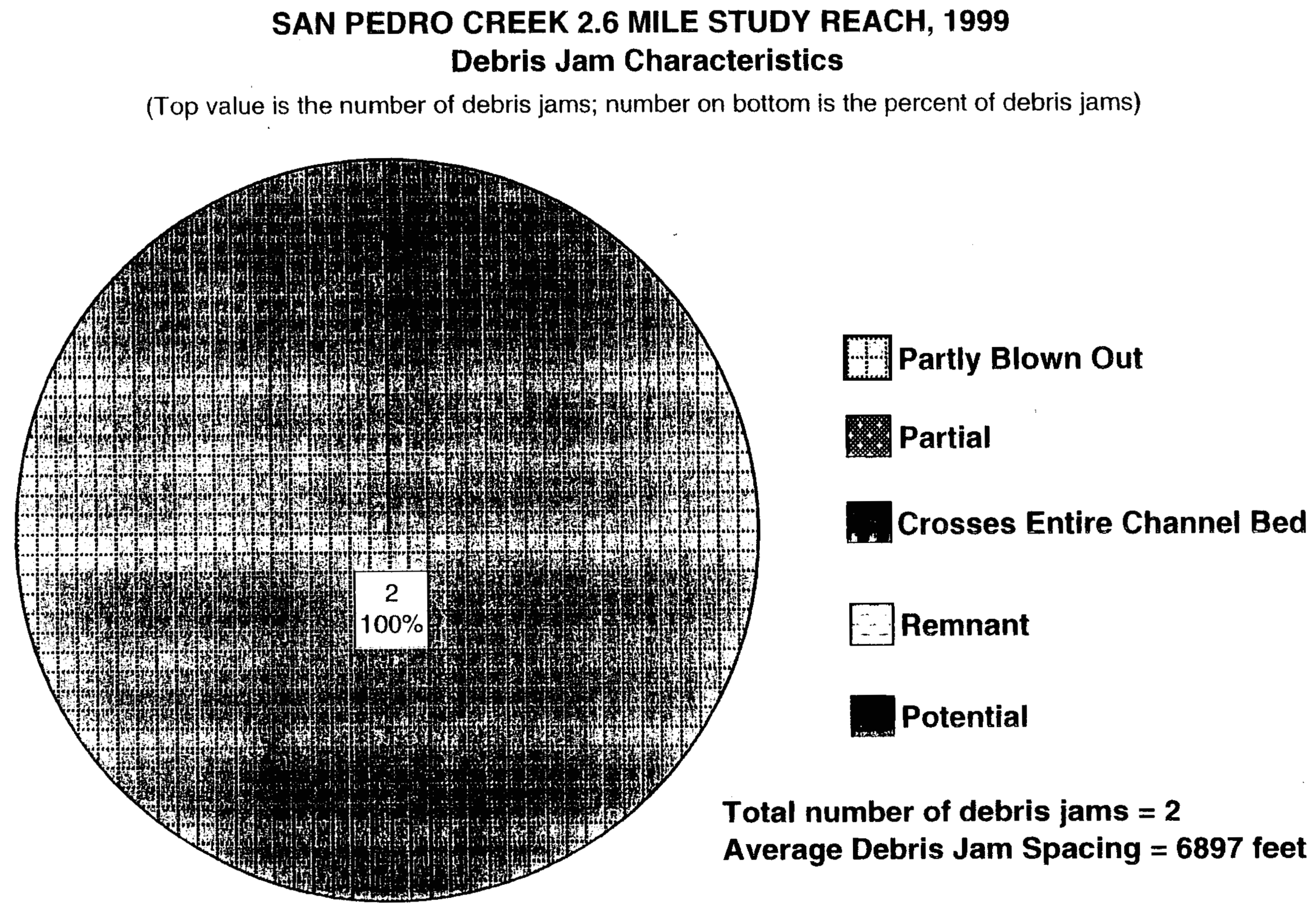


Figure 33. Debris Jam Characteristics

HOW WOOD ENTERS CHANNELS

The processes that supply wood to the channel need to be identified if an understanding of the recruitment and loss of wood to the system is desired. How LWD was supplied to San Pedro Creek was determined when possible. If the cause could not be established, we recorded the wood as float, meaning that it floated to present position. Several categories of LWD recruitment were devised. They include:

- bank erosion (lateral migration and undermining);
- landslides;
- rammed (uprooted and ripped form banks by the large floating debris);
- bent or leaning into the flow (functioning as LWD even though diameter may be less than 8 in);
- gravity (falls from windthrow, disease, or is hit by another tree;
- aggraded (deposited sediment fills around the tree trunk incorporating it into the active bed); and
- human-induced (lumber or stumps discarded into the creek, or constructed weirs, for example).

Number of LWD Types per Recruitment Process

The predominant mechanisms responsible for recruiting wood in San Pedro Creek are stratified by species in Figure 34. Most of the wood observed was counted as float but we were able to determine that bank erosion and leaning or bent into the flow were the most important ways that wood was recruited. The latter mechanism only involves the riparian vegetation of willow and alders that tend to grow near the bankfull elevation. Terrace bank erosion is the most likely mechanism for supplying the other species of trees that tend to grow on the higher terraces. A few LWD elements have been incorporated into the channel by aggradational processes.

Historically, San Pedro Creek would have had less accelerated rates of bank erosion in the past than in the present, the dominant LWD recruitment processes along the alluvial terraces may have been gravity and ramming by floating debris. If they were not dominant, their importance may have been at least as important as bank erosion. We consider that land use activities have caused a shift in rates and processes by which LWD is recruited.

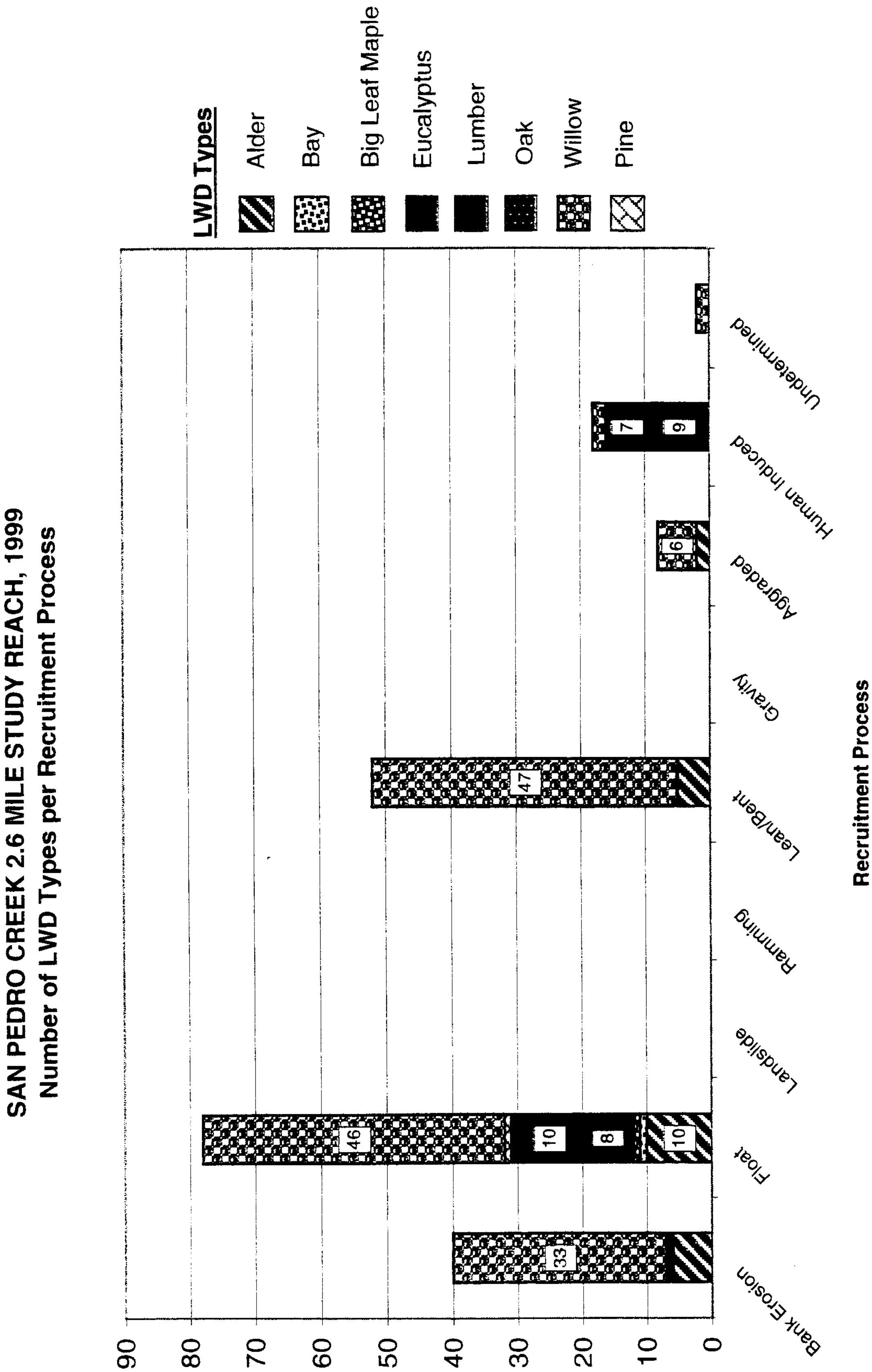


Figure 34. Number of LWD Types per Recruitment Process

Percent LWD Recruitment Process

The pie chart in Figure 35 simply summarizes the number and percent of LWD represented by the different recruitment processes for the entire Study Site. About 40% of the wood was counted as float, 52% were bent or leaning into flow, and 20% could be directly attributed to bank erosion. In the historical San Pedro Creek, when bank erosion rates were not as greatly accelerated, gravity and rammed by floating debris may have had more or at least similar dominance as an LWD recruitment mechanism. Leaning or bent trees were probably always important. Willow dominates all the different processes of input except for those that are human-induced. We note that we have seen increased efforts by people to use willow stakes to help stabilize eroding banks.

The loss of wood from the system has also changed. When the channel was less entrenched, much of it probably floated out onto the floodplain. That mechanism is now extremely rare and would only occur on the terrace banks (abandoned floodplains) in the drainage ditch portion of the creek during extreme floods.

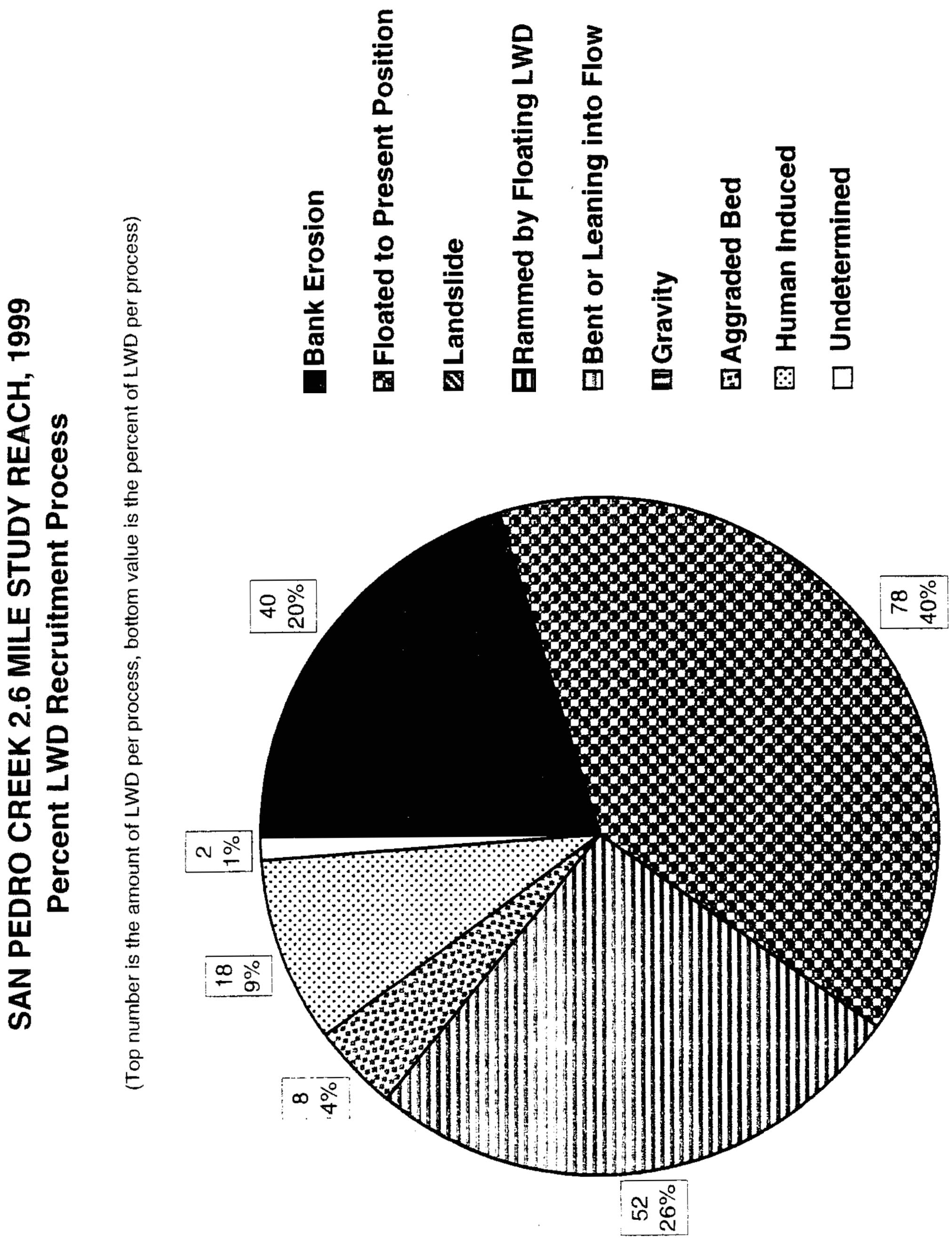


Figure 35. Percent of Different Recruitment Processes per LWD

CHANNEL STABILITY AND ROSGEN STREAM CLASSIFICATION

Using a broad brush approach to the stream classification system developed by Rosgen (1996), we have roughly attempted to identify different channel morphologies along the Study Site to identify reaches that are presently in an unstable form. We have simply used entrenchment ratios and width depth ratios to depict the Rosgen Stream Classes. For explanation of the classification system, see Rosgen (1996). We have included a diagram in the Appendix that depicts the different morphologies of the stream classes. For the purposes here and for the qualities we find in Bay Area channels, we have slightly modified the width/depth threshold and its degree of error for defining the different stream classes. Rosgen sites the threshold to be 12 with an error of +/- 2.0. Based upon discussions with Rosgen and measured field conditions, we use a threshold of 10 +/- 3.0. A brief description of the classes present in the study site follows. The A and D stream classes are not included because they were not observed at the Study Site. The C class was included in the descriptions because we believe that historically, San Pedro Creek above the willow grove was a C channel that had access to an extensive floodplain.

After Rosgen (1996) with modified thresholds for this project.

Stream Type	**Entrenchment Ratio (+/-0.2)**	**Width/Depth Ratio (+/- 3.0)**	Description
B	**1.4 – 2.2**	**>10**	Pool/riffle dominated channel with moderate gradient, moderate entrenchment, and stable banks, planform and profile
C	**>2.2**	**>10**	Pool/riffle and point bar dominated channel, slightly entrenched, with low gradient and well defined floodplain
E	**>2.2**	**< 10**	Pool/riffle, stable narrow and sinuous channel, slightly entrenched with low gradient and accessible floodplain.
F	**<1.4**	**>10**	Pool/riffle channel that is wide, unstable and highly entrenched with low gradient. Laterally unstable with high bank erosion rates.
G	**<1.4**	**<10**	Highly entrenched "gully-like' channel with moderate gradient that is deeply incised causing high

The previous table shows that the general characteristic of F and G type channels is their instability. G channels tend to be in a predominant downcutting mode. F channels are predominantly widening their banks. B, C and E channels have greater stability. It is important to recognize that a channel can change from one stream type to another. A stable B channel may have been in a G form, for example, until it achieved an appropriate geometry to move its water and sediment.

Stream Classes by Reach and Longitudinal Profile

We have plotted the extent of the different Rosgen Stream Classes by their distances along the Study Site in Figure 37a-d. We have incorporated the gradient derived form the topographic maps and the total amount of sediment supply per linear foot of stream for the 217 year period of interest. The purpose of this graph is to show where the channel types occur so that potential restoration efforts can be planned on a site-specific basis. For some restoration projects, it is useful to compare the geometric parameters of stable reaches to those of the unstable reaches. For example, cross sections could be surveyed in similar gradient reaches of F versus B type channels to establish the differences in geometry. This would be done if potential restoration plans call for reconfiguring the channel into a more stable form in order to reduce property loss or to minimize sediment supply, for example. This graph exemplifies how reference channel characteristics can be sought for certain slope and sediment size regimes. We caution that a true field survey of channel gradient is required for detailed restoration planning.

The reaches with the highest sediment supply are the reaches It is important to note that many of the reaches now classified as B type geometry may have been in a previously unstable F or G form. This graph only allows assessment of present status, not past history.

SAN PEDRO CREEK LONGITUDINAL PROFILE WITH MORPHOLOGIC ZONES AND STREAM REACHES FOR 2.6 MI STUDY SITE

Elevations downstream of Adobe Bridge are derived from USACE 1998,
while elvations upstream are derived from the 7.5' 1993 USGS Montara Mountain Quadrangle.
Slopes are determined from end points elevations of each Reach.

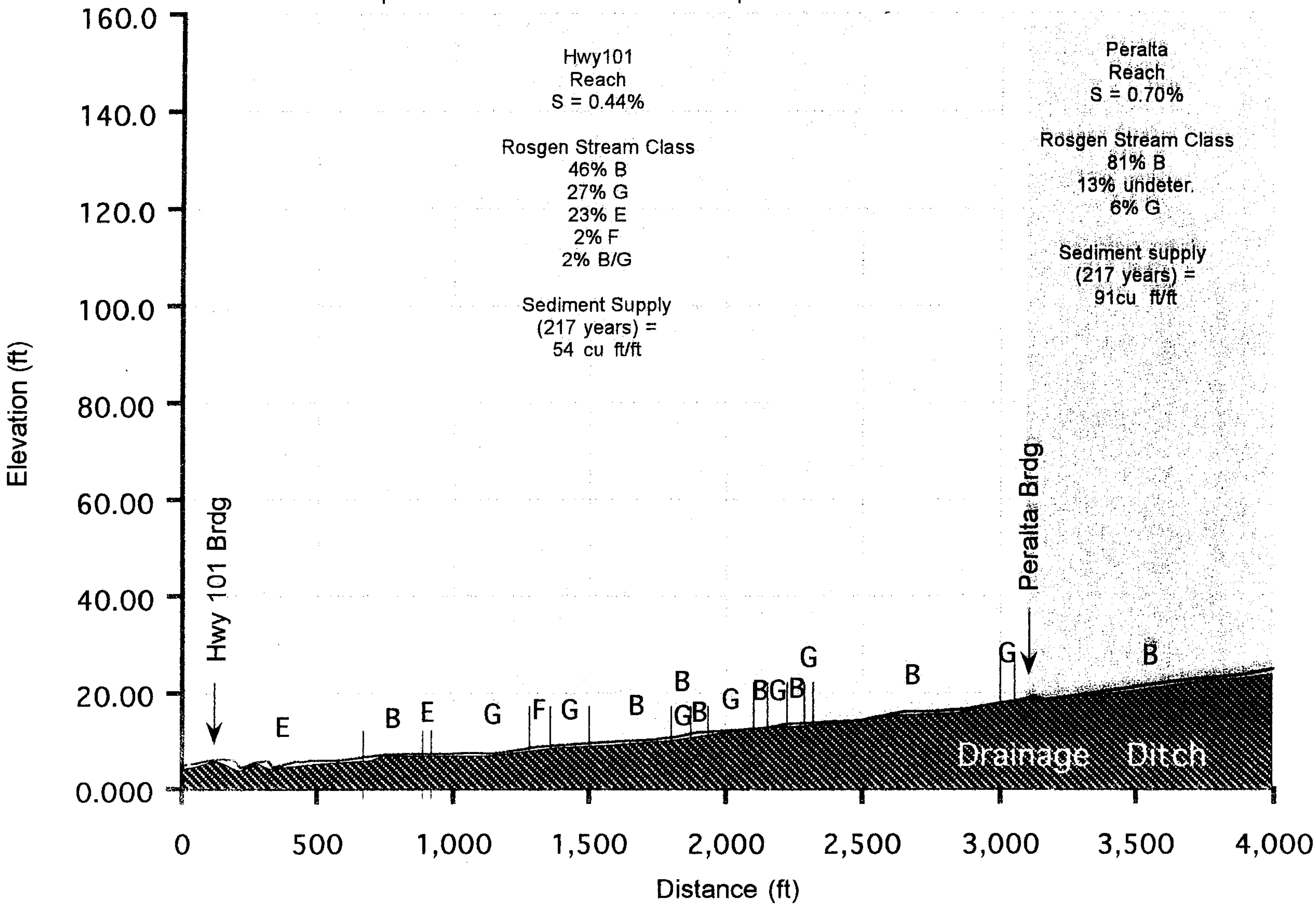


Figure 37A. Morphologic Zones and Stream Classes

SAN PEDRO CREEK LONGITUDINAL PROFILE WITH MORPHOLOGIC ZONES AND STREAM REACHES FOR 2.6 MI STUDY SITE

Elevations downstream of Adobe Bridge are derived from USACE 1998, while elvations upstream are derived from the 7.5' 1993 USGS Montara Mountain Quadrangle. Slopes are determined from end points elevations of each Reach.

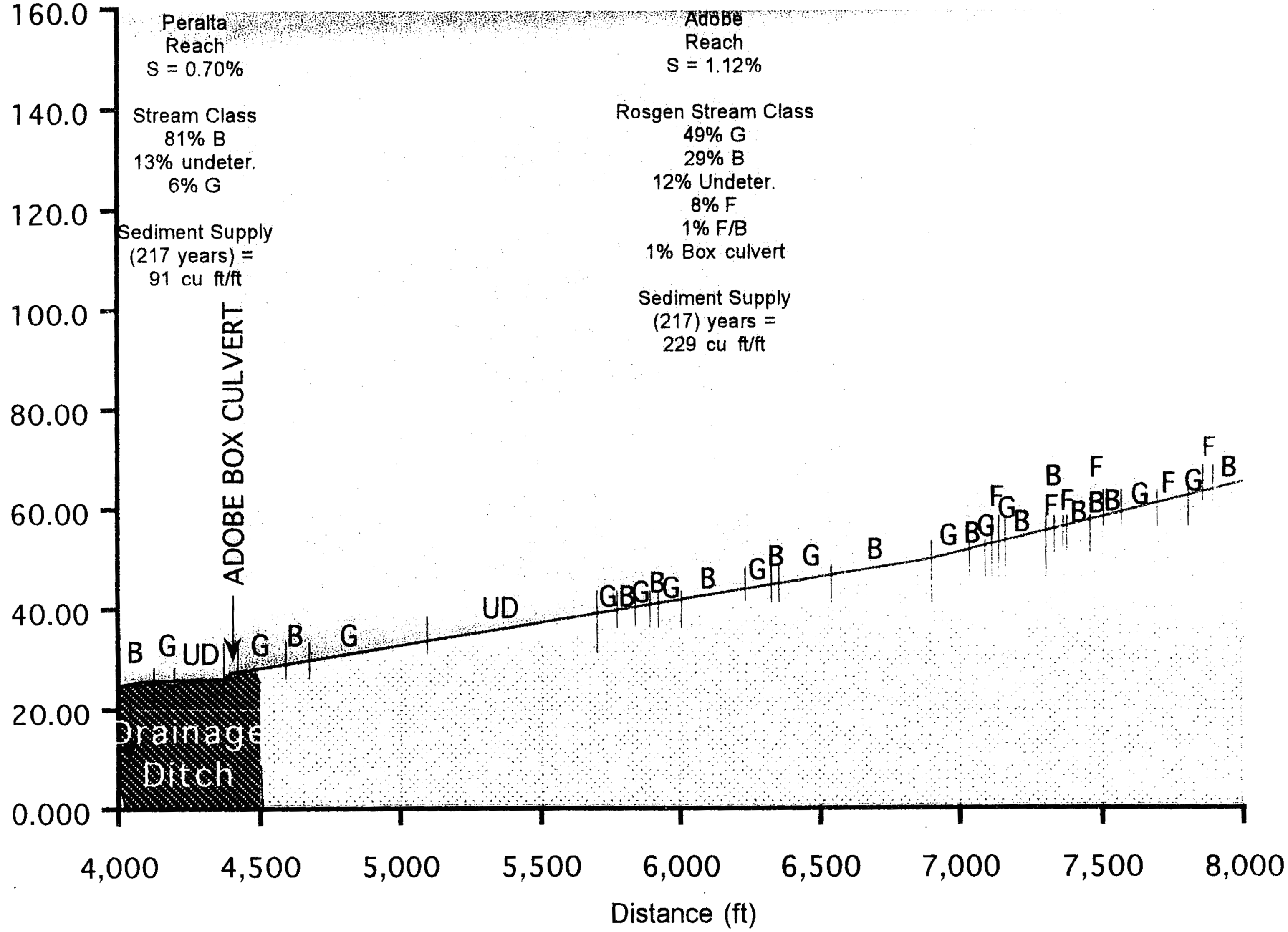


Figure 37B. Morphologic Zones and Stream Classes

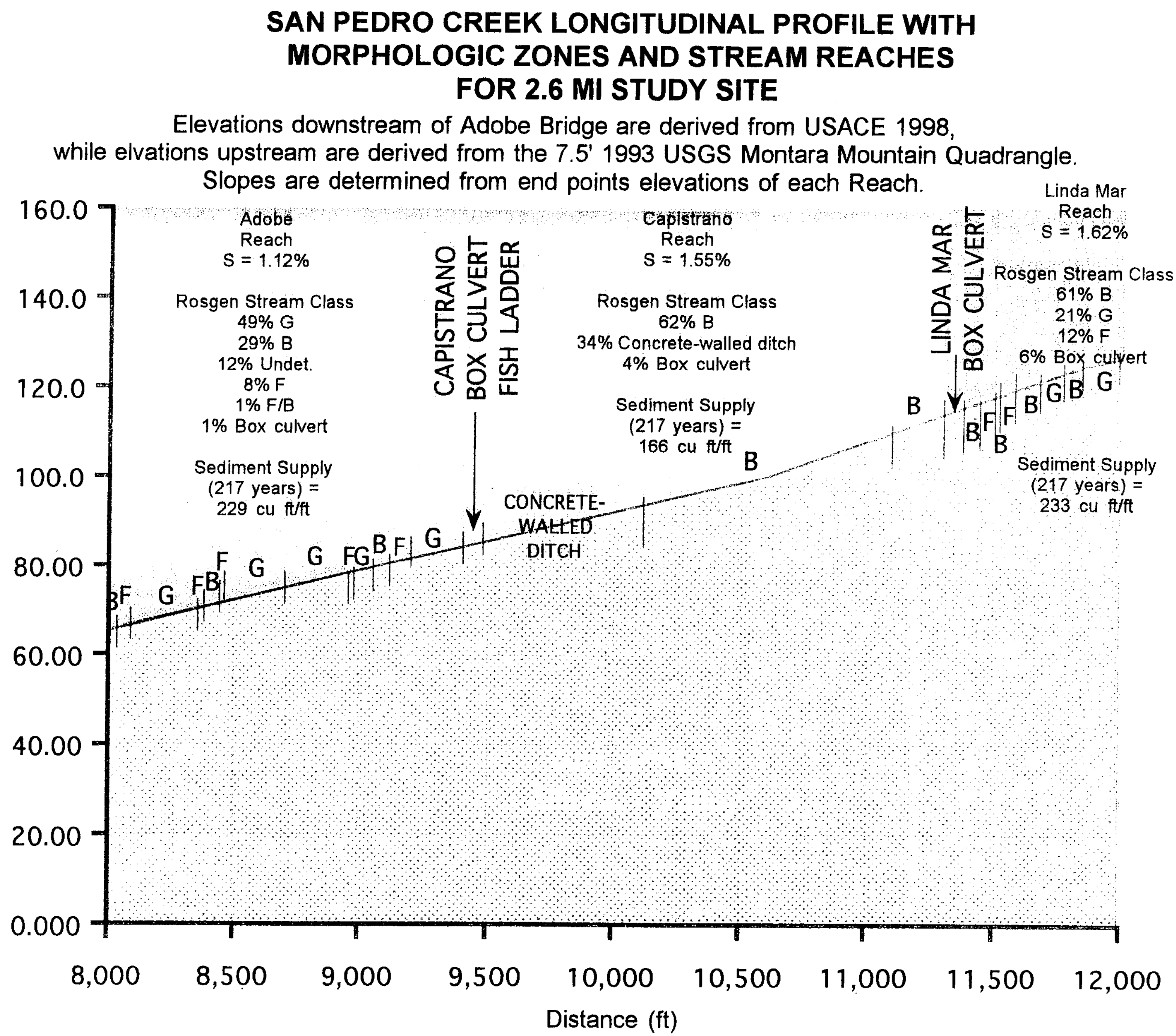
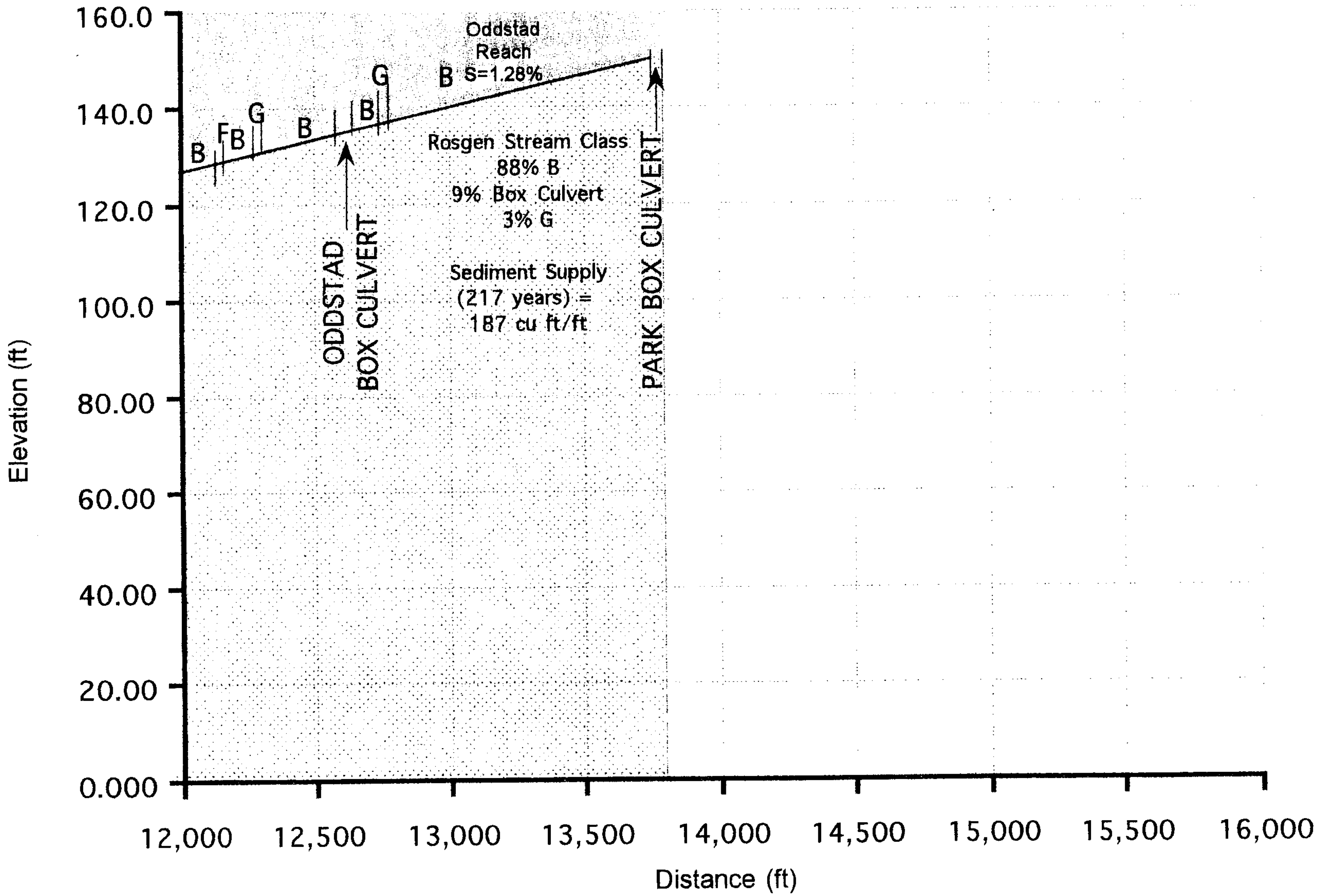


Figure 37C. Morphologic Zones and Stream Classes

Figure 37D. Morphologic Zones and Stream Classes

SAN PEDRO CREEK LONGITUDINAL PROFILE WITH MORPHOLOGIC ZONES AND STREAM REACHES FOR 2.6 MI STUDY SITE

Elevations downstream of Adobe Bridge are derived from USACE 1998,
while elvations upstream are derived from the 7.5' 1993 USGS Montara Mountain Quadrangle.
Slopes are determined from end points elevations of each Reach.



CONCLUSIONS

DISCUSSION OF LAND USE AND GEOMORPHIC CHANGE

San Pedro Creek Watershed (SPW) was first viewed by non-natives in 1769, in the month of October, typically the peak of seasonal drought for the Bay Area. At that time, the autumn base flow sank into the ground in a large marsh of cane grass that extended to sand dunes at the western extent of the valley. A high groundwater table maintained the wetland. A few trees in the beds of the arroyos and as well as some moderate-sized willows could be seen along the creek. The 1835 Barceno Diseño shows the San Pedro Creek flowing through a willow grove to Lake Mathilda, but the later 1838 DiHaro Diseño shows the creek ending upstream at the head of the willow grove. The first topographic depiction of SPW in 1853 also shows San Pedro Creek ending upstream of a willow grove with no channel connection to Lake Mathilda. By the time this map was made the land had already sustained impacts from 77 consecutive years of grazing and 71 years of agricultural farming. San Pedro Creek was already responding to changes in runoff and sediment supply that were influenced by reduced thatch cover in the grasslands, trampling of riparian and wetland areas by cattle, conversion of native bunch grasses to European annuals, plowing practices that created large areas of bare soil, water diversion, and the cessation of native people's land use practices such as frequent burning and plant harvesting. As a result of these many prior impacts, we caution that the 1853 map does not illustrate the natural pristine condition of San Pedro Creek or the distribution of riparian vegetation that existed prior to non-native settlement.

Today, it is not entirely clear what San Pedro Valley used to look like prior to non-native settlement. Investigations of this study suggest that Lake Mathilda may have been much larger or it may have been an ephemeral lake that would come and go as dunes were built and eroded by storm waves or flood flows. Wetlands of this kind may have been important nursery and feeding habitat as temporary holding areas for smolts awaiting their seaward migration. Non-native land use practices could have caused the channel to respond to increased runoff. Increased runoff and accelerated sediment supply into the lake may have caused a delta to rapidly build and become colonized by willows and/or alders. This may be an explanation for the sausal that seems to expand in size through the sequence of early maps. The creek may have braided and separated into several distributaries beneath the sausal, as its capacity to carry high sediment loads was overwhelmed. Erosion in the reach above the delta may be a reason for documented accounts, by Padres of bridge repair and replacement only six years after farming began. We suggest that the channel was responding to increased runoff and instream structures and that it was probably less than 5 ft deep at the time of early non-native settlement. The valley floor may have been a functional floodplain in the middle of San Pedro Valley, later separated by channel incision.

By 1790, a deep ditch that was 1375 feet long was constructed to drain the land. This may have been the first effort to disconnect San Pedro Creek from its wetland. Modern and more extensive ditching took place again during the farming era. It is unclear to us when San Pedro Creek was actually moved into its present drainage ditch, but this impact may have been the most significant because it initiated a cycle of downcutting and channel entrenchment. The channel gradient was steepened, as the channel cut down it could hold larger floods that could exert more shear stress on the bed and banks, and as the channel cut down more of the water table drained into the channel.

By the 1860's the Adobe land was subdivided and leased to farmers and dairy ranchers. Additional tributaries were probably ditched and moved to the valley sides. An increasing number of flashboard dams were placed across the creek to supply reservoirs for irrigation. As irrigation systems became modernized the size of the reservoirs probably increased. Nearly all available land along the valley flat was plowed and planted with crops and the width of riparian corridors was reduced as much as possible, sometimes restricted to just the inner banks that had formed within the entrenched channel system. As flashboard dam and bridge structures were increasingly placed across San Pedro Creek, the channel would adjust its local geometry to another wave of impacts. This maintained instability and high sediment loads. Removal of water during summer drought would certainly have diminished available salmonid habitat.

Suburbanization of SPW during the mid 1900's initiated yet another surge of channel adjustments. Increased runoff from impervious areas and the faster delivery of runoff from gutters and miles of culverts caused floods to increase in magnitude and frequency. As banks continued to erode, more instream bank revetments were placed along the channel banks. These structures continue to increase today, while many of the relict structures of abandoned dams and deteriorating revetments continue to cause new channel adjustments as they collapse into the stream. Some, however, have actually increased the number of pools but they have also increased bank erosion and may not provide the desirable diversity and cover that would be gained from natural or wood-formed pools.

We have listed below some of the obvious cause and effect relationships that have influenced SPW. It is always important to remember that increased erosion rates in one part of the watershed have the potential of increasing sedimentation rates elsewhere. San Pedro Creek currently appears to have the capacity to transport most of its sediment load out of the watershed to the Pacific. How this increased sediment supply has influenced marine habitat is beyond the scope of this study but should not be discounted as unimportant. Furthermore, although the inputs of nutrients, pathogens and toxins as they affected water quality in San Pedro Creek are beyond the scope of this project, the sources and processes that supply them must be defined for maximum success of future restoration efforts.

Important land use impacts in San Pedro Valley and some example channel responses

- Cattle grazing = increased runoff, increased fine sediment load from hillsides, headward erosion of tributary channels = increased drainage density and more flow to mainstem channel = internal mainstem channel adjustments and increased sediment supply
- Construction of drainage ditch = increased erosion and sediment supply by initiating an incision/entrenchment cycle in upstream channel network
- Entrenchment = loss of floodplain = channel adjustments and increased sediment supply
- Concrete walls = loss of riparian vegetation, loss of pools, increased water velocity = loss of fish winter refuge during high flows and increased bed incision = increased sediment load
- Trapezoidal channel geometry = over-widened bankful width, sediment deposition, loss of pools and base flow
- Plowing = increased fine sediment load from raindrop splash, surface erosion and overland flow

- Destruction of riparian vegetation = increased bank erosion = increased sediment supply and increased water temperature
- Lack of riparian vegetation replacement = loss of LWD recruitment, unchecked bank erosion, and increased water temperature
- Lack of LWD recruitment = greater sediment transport, loss of pools, less sediment storage = increased bed incision
- irrigation reservoirs = loss of summer flows for fish and wildlife
- bank revetments and instream structures = possible fish migration barriers, increased bank erosion on opposite banks and/or at endpoints of structure = increased sediment supply
- urbanization = impervious surfaces = increased runoff causes channel adjustments = increased sediment load
- disconnection of wetland = loss of summer nursery habitat for smolts, loss of biological diversity and wildlife habitat
- Loss of tributary channels to miles of box culvert = loss of fish/wildlife/riparian habitat, increased flow velocity, reduced sediment load from length of channel in culvert = increased erosion and channel adjustment downstream of box culvert

RECOMMENDATIONS

1. Where possible, reduce accelerated rates of bank erosion and bed incision to reduce property loss and input of fine sediment to the channel, but minimize the use of unnatural instream structures for stabilization. Instead, consider reshaping the channel cross section to a stable form, use biotechnical stabilization methods, or use boulder veins to direct flow away from eroding banks. Channel reshaping could be accomplished by surveying cross sections in the stable B type Rosgen Stream Class to potentially construct similar geometry (where appropriate) in the F and G classes.

2. Increase the width of the riparian buffer along the channel, especially where vegetation is presently missing. Promote the replacement of non-native invasive vegetation with native species to improve riparian habitat.

3. Increase the potential for LWD recruitment by not removing or modifying LWD unless it threatens a structure or causes backwater flooding at bridges, and by performing the previous recommendation.

4. The longitudinal profile of the mainstem channel should be surveyed to establish future monitoring stations that will show changes in bed elevation and correctly define terrace heights and stream gradient. The profile should be detailed enough to define pool/riffle morphology.

5. Consider long-term funding solutions for 1) restoration projects; 2) future bridge designs that will not interfere with large floods, the passage of LWD, and the transport of sediment; 3) subsidies and incentives for landowners to stabilize banks using methods discussed in recommendation #1.; and 4) long-term monitoring San Pedro Creek as an Observation Watershed for future change.

6. The rest of San Pedro Creek Watershed should be assessed for sources of sediment resulting from land use and instream activities upstream of the Study Site. The quality of water and habitat in mainstem and tributary reaches should be assessed. It is important that the remaining fragments of high quality be maintained into the future.

7. Consider opportunities to ameliorate increased, flashy flows from the urban areas by constructing floodplains, off-channel habitat, wetlands, and lakes (consider the previous functions of Lake Mathilda).

8. Redesign the Capistrano fish ladder and downstream pool. Also modify or redesign the upstream 640' – long concrete walled channel to improve fish migration by incorporating resting areas into the channel geometry.

9. Investigate whether there is potential to daylight portions of North Fork to increase salmonid habitat.

10. Historical questions about the extent of wetlands or frequency of native burning practices cannot be answered by this study, but a program of coring select parts of Lake Mathilda and the valley floor could provide some resolution.

ACKNOWLEDGMENTS

We would like to acknowledge the following people for their time, knowledge, and sincere interest. Without them we would have lacked the resources and background necessary for an effective geomorphic analysis: The San Francisco Bay Regional Water Quality Control Board, and the City of Pacifica, for their financial contributions; Todd Featherstone, San Francisco Estuary Institute for his work on the Streamline Graphs; watershed residents Shirley Dyer, docent at the Sanchez Adobe, and Paul Azevedo of the Pacifica Historical Society, who both shared their historical knowledge of San Pedro Valley; John Culp, San Francisco State University geography graduate student, for his cultural analysis of San Pedro Valley; Jerry Davis, watershed resident, San Francisco State University geography professor, and San Pedro Creek Watershed Coalition President for his dedication to the watershed, his GIS support, and a much-needed ride; Paul Jones, watershed resident and EPA Life Scientist, for the vision to make the geomorphic analysis happen; and to concerned citizens of Pacifica for their interests in the life that the land supports.

GLOSSARY

Aggradation	The long-term process of building up a surface by deposition of sediment.
Alluvial fan	An outspread cone-shaped, gently sloping mass of alluvium deposited by a stream due to a rapid change in slope or valley width.
Alluvium	Stream deposits made by streams on river beds, flood plains, or fans that may include boulders, gravels, sands, silts, and clays.
Anastamosing	A stream channel that branches and joins again at the main channel.
Armoring	Coarse sediment on the channel bed surface that does not usually move at bankfull discharges.
Bankfull	The incipient elevation of the water surface of a stream as it begins to flow onto its floodplain. The flow may have a recurrence interval of about 1.3 t 1.7 years.
Confinement	The relationship between valley width and bankfull width.
Cross section	The geometry of a river channel or other fluvial feature usually measured at right angle to the bank.
D50	Median grain size of sediment measured at a location being described. The particle size is measured along the intermediate axis.
Degradation	The long-term lowering of a surface by erosive processes, especially by flowing water.
Deposition	The short-term laying down of material previously entrained in flowing water as a result of a decrease in the energy needed for transport.
Entrenchment	The down-cutting of a stream into its floodplain alluvium or bedrock that causes a reduction in the rate of lateral migration and an increase in contained flood waters.
Entrenchment ratio	The floodprone width divided by the bankfull width.
Floodplain	A flat bench or plain at the edge of the banks that floods an average of every 1.5 years.
Floodprone	Description of an area that is likely to be inundated during storm flow that lies within the channel banks or floodplain.
Floodprone width	Floodprone width is the measured width between the banks at twice the maximum bankfull depth.
Incision	The short-term process of down-cutting which, if occurring at a faster rate than deposition, may eventually lead to permanent degradation of a channel bed.
Lateral migration	The action of a stream swinging from side to side, impinging against and eroding its banks.
Longitudinal profile	The elevation of the stream bed relative to its distance along its valley.
Large Woody Debris (LWD)	For the purposes of this project large woody debris is wood greater than 8 in diameter and is supplied to the stream from adjacent trees.
Planform	The outline of a shape viewed from above.
Revetment	Any type of retaining structure which increases bank stability e.g. rip-rap, concrete, wire mesh.
Rosgen Stream Class	A system of stream classification that defines streams by their morphology.
Sediment budget	The quantitative description of sources, sinks and riverine transport. Taking into account the errors associated with the definition and quantification of each of the terms, the sum of all the terms will add to zero. This represents the conservation of mass.

Sediment rate	Transport, accumulation, or erosion of a volume or mass of sediment expressed per unit time.
Terrace	A relatively level bench or step-like surface that was constructed by a river and represents an abandoned floodplain.
Thalweg	The deepest point of a channel at any given cross section. A thalweg profile is a survey of the deepest point in the channel bed.
Watershed	Area defined by a topographic drainage divide within which water from rainfall flows toward a common point.
Width / depth ratio	The relationship between the width of the channel and the depth of the channel at bankfull stage.

REFEREENCES

USACE, 1998.

USACE, 2000. San Francisco District Projects, San Pedro Creek, Section 205, Project Manager Eric Bluhm, web site: USACE.army.mil/projects/sanpedro.html, updated 4/2000.

BioSystems Analysis Inc., 1991. 1990 Archeological Investigation of Sanchez Adobe Park Historic District, for County of San Mateo, Dept. of Environmental Management, Parks and Recreation Division.

Brabb, E.E., and E.H. Pampaeyan, 1972. Preliminary geologic map of San Mateo County: U. S. Geological Survey Miscellaneous Field Studies Map MF-328, 10 p.

Brown, A.K., 1957. Before the Sánchez Adobe. *La Peninsula* Journal of the San Mateo Historical Assoc., San Mateo. 9(2).

Brown, J., 1961. From cattle to cabbages. *La Peninsula.* 11(1): 4-5. Journal of the San Mateo Historical Assoc., San Mateo.

California Division of Mines and Geology, (1982). Special Studies Zones, Montara Mountain Quadrangle, scale 1:24,000.

Chavez, D., S.A. Dietz and T.L. Jackson, 1974. Report of the 1974 Archeological Excavations at the Sanchez Adobe, submitted to the San Mateo County Dept. of Parks and Recreation. Partial copy in Pacifica history files of the Pacifica Library.

Culp, J., 1999. Shellmounds to cul-de-sacs: the cultural landscape of San Pedro Valley, Pacifica, Calif., manuscript for Geography 820, San Francisco State.

de Haro, F., 1838. *Diseño del Terreno de San Pedro.* Copy on file at the San Mateo County historical Assoc. Library, College of San Mateo, and San Mateo.

Dietz, S.A., 1979. Report of archeological investigations at Sánchez Adobe Park Historic District, Archeological Consulting and Research Services, Inc. Contributions from B. Bredemeyer, R. Miliken, D. Simons, and L. White.

Drake, R.J., 1952. Samplings in history at the Sanchez Adobe, San Mateo County, California. *El Palacio.* 59-60:19-29.

EOA, Inc., 1998. Impervious cover as a watershed management tool for San Mateo County watersheds, 1410 Jackson St., Oakland, CA 94612, 8 p and Appendices.

Gehre, J.S., 1968. The geography of selected patterns of agriculture in San Mateo County, California. San Francisco State University: MA Thesis.

Hynding, A. 1982. *From frontier to suburb: the story of San Francisco Peninsula*: Belmont CA. Star Publishing

Howard, T.R., J.E. Baldwin II and H.F. Donley, 1982. Landslides in Pacifica, California, caused by the storm, pages 163-183, *in* Ellen, S. D., and G. F. Wieczorek eds., Landslides, floods and marine effects of the storm of January 3-5, 1982, in the San Francisco Bay Region, California. Professional Paper 1434. Washington: U. S. Government Publishing Office.

Langhoff, J., 1996. The Ocean Shore Railroad: Reaches the Beaches, web site: www.ci.pacifica.ca.us/history/railroad.html

Leopold, L.B., 1994. View of a River: Harvard University Press, Cambridge, MA, 298 pp.

Miller, C.T., 1971. Evolution of the Cultural Landscape of the Half Moon Bay Area, California: San Francisco state University: MA Thesis.

Pacifica Tribune, 1995. Pacifica History Gift Calendar.

Pacifica Tribune, 1997. Pacifica History Gift Calendar.

Pampayen, E.H., 1994. Geologic Map of the Montara Mountain and San Mateo 7-1/2', Quadrangles, San Mateo County, California, U.S. Dept. of the Interior, U.S. Geological Survey, Miscellaneous Investigations Series, Map 1-2390 and accompanying text, 19 p.

Rosgen, D., 1994. Applied River Morphology: Wildland Hydrology, Pagosa Springs, Colorado.

San Mateo County Parks and Recreations Division, not dated. San Pedro Valley Park, free public pamphlet from Environmental Services Agency

Savage, d., 1983. The land called Pacifica, Friends of the Sanchez Adobe Historic Site: Historical Paper Number 1. Pamphlet from the Pacifica history files in Pacifica Library.

Stanger, F.M., 1963. South from San Francisco, San Mateo County, California *Its history and heritage*, published by San Mateo County historical Association, MCMLXIII, 73 p.

Stanger, F.F., and A.K. Brown, 1969. Who discovered the Golden Gate? The explorer's own accounts. San Mateo County Historical Association. San Mateo.

US Army Corps of Engineers, 1997. Final Detailed Project Report Environmental Impact Report/Environmental Impact Statement San Pedro Creek Flood Control Project, Volume I: USACE San Francisco District and City of Pacifica, California, October.

US Army Corps of Engineers, 1998. Final Detailed Project Report Technical Appendices San Pedro Creek Flood Control Project: Volume II USACE: San Francisco District and City of Pacifica, California, January.

US Coast Survey, 1853. Map of part of the Coast of California from Point San Pedro northward, A.D. Bache supervisor, scale 1:10,000.

US Geological Survey, 1949. Montara Mountain 7.5' Quadrangle, U.S. Geological Survey.

US Geological Survey, 1956. Montara Mountain 7.5' Quadrangle, Photo revised 1968 USGS.

US Geological Survey, 1993. Montara Mountain 7.5' Quadrangle, U.S. Geological Survey.

APPENDIX

Streamline Graphs Key

Streamline Graphs

Photographs

Streamline Graph Key

Bank Features

- Stable bank
- Actively eroding bank
- Eroding canyon slope
- Active landslide
- Quaternary Alluvium
- Eroding Quaternary Alluvium
- Concrete
- Rip rap
- Rip rap debris
- Sackcrete
- Gabion
- Wood fence
- Brick
- Wood
- Rock wall
- Cyclone fence
- Sheet metal
- Other

Abbreviations

tr - Trail
dst - Downstream
ust - Upstream
cpp - Corrugated plastic pipe
cmp - Corrugated metal pipe
rcp - Reinforced concrete pipe

Large woody debris

O Pool greater than 1' deep

X Debris jam

Bed Features

- Bedrock in bed
- Clay (< .004 mm)
- Silt (.004 - .062 mm)
- Sand (.062 - 2 mm)
- Very fine gravel (2 - 4 mm)
- Fine gravel (4 - 8 mm)
- Medium gravel (8 - 16 mm)
- Coarse gravel (16 - 32 mm)
- Very coarse gravel (32 - 64 mm)
- Small cobble (64 - 128 mm)
- Large cobble (128 - 256 mm)
- Small boulder (256 - 512 mm)
- Large boulder (> 512 mm)
- Rip rap
- Rip rap debris
- Vortex rock weir
- Concrete
- CMP (Corrugated metal pipe)
- Roots
- Wood
- Organic matter
- Grass
- Typha
- Sedge
- Quaternary Alluvium
- Willow
- Herb

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San Pedro Creek Streamline
Graph Key

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- Streamline graphs
- photographs